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Noise and hearing in a trackless-mining environment

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SYNOPSIS

Noise is a form of pollution arising mainly from the activities of man. One such activity is mining, in which man, as in many of his other activities, uses machinery of various kinds to achieve safe, healthy, and economic production.

Trackless mining makes use of an advanced state of techology over that required in traditional mining methods. One of the advantages of the former, as distinct from any disadvantages it may have, is a reduction in noise levels, the number of people exposed to noise, and the duration of their exposure to noise.

This paper briefly examines why noise is a problem and what various countries are doing about it in terms of standards, codes of practice, and regulations. It also investigates the extent to which noise is a problem in mining and how trackless mining alleviates this problem.

The question is then posed as to whether South Africa is not setting too high a standard at this stage of its national development by comparison with what is being done by other, more-advanced countries.

SAMEVATTING

Geraas is 'n vorm van besoedeling wat hoofsaaklik uit die mens se bedrywighede voortspruit. Een sodanige bedrywigheid is mynbou waarin die mens, soos in baie ander van sy bedrywighede, verskillende soorte masjinerie gebruik om veilig, gesonde en ekonomiese produksie te bewerkstellig.

Spoorlose mynbou maak gebruik van gevorderde tegnologie vergeleke met dié wat vir tradisionele mynboumetodes nodig is. Een van die voordele van eersgenoemde metode, afgesien van enige nadele wat dit mag inhou, is 'n verlaging van die geraaspeile en 'n vermindering van die aantal mense wat aan geraas blootgestel word, en van die duur van hul blootstelling aan geraas.

Hierdie referaat gaan kortliks na waarom geraas 'n probleem is en wat verskillende lande in terme van standaarde, gebruikskodes en regulasies daaromtrent doen. Dit ondersoek ook die mate waarin geraas 'n probleem in mynbou is, en hoe spoorlose mynbou hierdie probleem verlig.

Die vraag word dan gestel of Suid-Afrika nie in hierdie stadium van sy nasionale ontwikkeling 'n te hoë standaard stel vergeleke met wat deur ander meer gevorderde lande gedoen word nie.

Introduction

For a variety of technical and economic reasons, trackless mining is being practised to an increasing extent in South Africa. One of the consequences of this relatively new method of mining concerns noise and hearing.

The forms of equipment used, be they rockdrills or load–haul–dump (LHD) units, are less noisy than their traditional counterparts. They are also more productive and can therefore complete a given amount of work in a shorter time with fewer people. So, by comparison with traditional methods and equipment, trackless mining improves the situation with regard to noise and hearing. In some situations, trackless mining cannot be practised for technical reasons but, in the main, economics is the deciding factor on when and where trackless mining will be used. The question whether trackless mining is implemented or not depends on whether the price that society is willing to pay for the product will cover the costs of production, tax, and profit. This is also related to the grade of ore being mined and the scale of operation.

Trackless mining was first introduced to South Africa in the 1960s in hardrock base-metal mining, mainly at Prieska. The coal mines are also using trackless mining, but the mining of coal, which is soft, presents less of a noise problem. South African hard-rock gold mines have been experimenting with trackless mining since the early 1970s. In gold mines operating on wide orebodies, this form of mining has reached a point where it is now responsible for some 70 per cent of the underground production at Western Areas Gold Mine and some 60 per cent at Randfontein Estates[1].

In gold mines operating in narrow reefs, trackless equipment is being put to use in developing the tunnels required. Some of these mines are experimenting with trackless mining for the stoping operation, and one can therefore foresee an increasing use of trackless mining, even under these more difficult constraints. This in the context of noise and hearing is an advantage. However, disadvantages are claimed[2] for diesel-powered and electric-powered trackless equipment because of the heat generated and the gas and particulate matter emitted.

Understanding Noise

Noise can be defined as sound that causes problems. The problems consist, firstly, in various forms of annoyance that noise gives rise to and, secondly, the impairment of hearing that may result from long exposure to high noise levels.

Hearing Impairment

Hearing impairment is of two kinds. The first kind affects the ears' capability to hear low-frequency sounds of from about 500 to 3000 Hz, and this limits the ability to listen to the spoken word. This impairment is a hindrance to occupational and social activity. The second

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kind of hearing impairment reduces the ears' capability of hearing higher-frequency sounds, from about 4000 to 8000 Hz and more. One's ability to hear these frequencies adds to the pleasure of listening to music and the sounds of nature, and might be regarded as a secondary ability.

Hearing impairment is monitored by audiometric testing. Some of the results are used in the calculation of the binaural hearing impairment (BHI) of a person. This is a measure of the inability of a person to hear speech and is expressed as a percentage. A hearing impairment of up to 25 per cent BHI is regarded as normal, and allows for the effects of aging (presbycusis) and exposure to noise below a recognized standard level and duration. A person with 30 per cent BHI would, on this basis, have a 5 per cent permanent disablement for which he could receive compensation, depending on whether he lives in a country that makes payments for such a disability or not.

Noise Standards

The problems of noise have gradually become worse throughout the world, both in the general environment and in the working place. Some countries have recognized it as a form of pollution requiring some sort of remedial action. These countries have studied and researched the situation, and have published various national standards. The standards that are relevant to this paper are those pertaining to occupational noise. Such standards are but a first step in an ongoing process to progressively reduce noise levels in the working place, to reduce the length of exposure to noise, to monitor the hearing ability of people exposed to occupational noise, and to encourage hearing conservation in cases where noise levels and durations have little scope for improvement.

The next step has been for countries to issue codes of practice based on the national standards. These codes do not have the force of law, but are often negotiated between the State and industry to achieve a result that is acceptable from the points of view of both the cost of noise-control measures and the cost of hearing impairment.

The final step is for countries to enact regulations that are legally binding on industry. This final step requires careful consideration in terms of what can be achieved with the resources available and the respective costs that are likely to be incurred.

As can be seen from Table I, South Africa is one of the few countries to have enacted regulations pertaining to occupational noise in industry. In terms of the noise in mines, it is among the many countries that have not yet enacted regulations. However, it is known that the Government Mining Engineer and the Minister of Mineral and Energy Affairs are proposing to have regulations passed in the near future concerning noise in mines.

Equivalent Noise Level

At this point, it is important to understand the definition of the various noise levels specified by different countries and the considerations upon which they are based. The level specified is generally based on an equivalent noise exposure for an 8-hour working day in a 40-hour working week for a 40-year working period. This means that a certain accepted percentage of people would be suffering a binaural hearing impairment in excess of 25 per cent, but the rest of the population would not have this problem. For example, the International Standards Organisation in its report ISO 1999 (1982) estimates that, at an exposure of 90 dB(A)Leq, 11 per cent of the persons exposed would have a hearing handicap; at an exposure of 85 dB(A)Leq, 3 per cent of persons would have a hearing impairment; and, at 80 dB(A)Leq, nobody would be affected.

The rationale behind the use of *Leq* is based on the assumption that damage to hearing is proportional to the total cumulative sound energy received by the ear. Sound waves are a form of energy and, although minute compared with other forms of energy, it is this energy that does the damage. Hence, to assess and control exposure to this risk of damage, one needs a measure that takes both sound level and duration into account. This measure is the equivalent continuous level of sound pressure that would cause the same amount of energy to be received—that is, it would have the same damaging effect on hearing as the varying noise to which the ear is actually exposed. This measure is denoted by Leq. If the noise level in a working area is reasonably steady and constant, it can be measured on a simple sound-level meter. If it varies in a random manner (the more usual situation), an integrating sound-level meter is used, or the total dose can be recorded during a working shift on a personal noise-dose meter.

It is important to appreciate that the energy received by the ear, being a combination of sound-pressure level and duration, can be either a high sound-pressure level for a short period or a lower level for a longer period—the damage is the same. Thus, a man working an 8-hour shift at an Leq of 85 dB will receive the same amount of energy, and suffer the same amount of damage to his hearing, as he would in 2 hours if the noise were 91 dB, and in only 15 minutes if the noise were 100 dB.

As shown in Fig. 1 and Table II, the 8-hour base varies between 85 and 90 dB. The choice of base is a question

TABLE I
STANDARDS OF NOISE LEVELS IN VARIOUS COUNTRIES

Country and regulation	Noise level for an 8 h day dB(A)	Half the exposure time for each increase of dB
USA:		
Regulation for industry and mines	90	5
Canada:		
Regulation, but not all provinces	85	5
Great Britain:		
Code of practice recommended for industry and mines	90	3
European Community		
Code of practice recommended for industry and mines	90	3
Australia		
Standard recommended	85	5
South Africa		
Regulation for industry and proposed regulation for mines	85	3

of the percentage risk of hearing impairment that is found acceptable. The halving of the daily exposure duration by steps of either 3 or 5 dB is also a matter of choice. This choice is based on whether one accepts, on strictly theoretical grounds, that an increase of 3 dB represents a doubling of the sound energy and therefore requires a halving of the exposure duration. The other, more lenient view is that, after an 8-hour working day, a person has 16 hours within which his ears can rest and recuperate, and it is therefore reasonable to allow a 5 dB increase for each halving of the exposure duration.

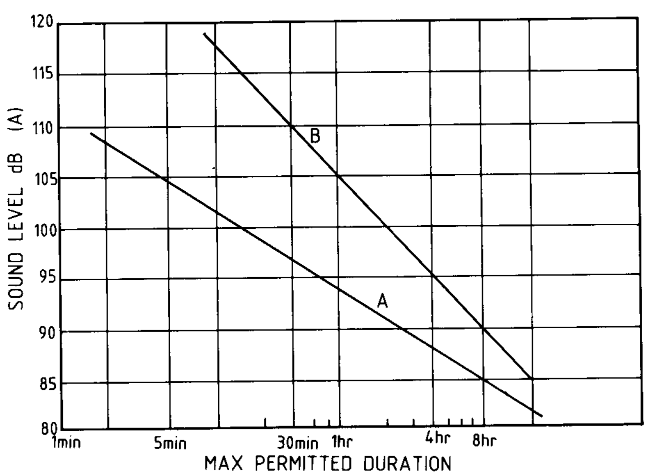

Fig. 1—Sound level and duration (A South African standard, B US standard)

TABLE II
VARIOUS STANDARDS OF SOUND LEVELS AND ASSOCIATED EXPOSURE DURATIONS

(A) 85 dBA base with 3 dBA steps		(B) 85 dBA base with 5 dBA steps	
Sound level	Duration	Sound level	Duration
85	8 h	85	8 h
88	4 h	90	4 h
91	2 h	95	2 h
94	1 h	100	1 h
97	30 min	105	30 min
100	15 min	110	15 min
103	7,5 min	115	7,5 min
106	3,75 min	120	3,75 min
109	1,875 min		
112	56 s		
115	28 s		
118	14 s		
121	7 s		

(C) 90 dBA base with 3 dBA steps		(D) 90 dBA base with 5 dBA steps	
Sound level	Duration	Sound level	Duration
90	8 h	90	8 h
93	4 h	95	4 h
96	2 h	100	2 h
99	1 h	105	1 h
102	30 min	110	30 min
105	15 min	115	15 min
108	7,5 min	120	7,5 min
111	3,75 min		
114	112 s		
117	56 s		
120	28 s		

Noise from Rockdrills

The manufacturers of rock-drilling equipment have been testing the noise characteristics of their equipment for a considerable time, especially since noise has become a matter for concern. The tests are conducted according to a recognized code, one of which is the CAGI-NEUROP test code[3] (Compressed Air and Gas Institute (USA) and the European Committee of Manufacturers of Compressed Air Equipment).

These tests are conducted on the surface in an environment as close to a free field situation as possible. It is required that the rock drill should be drilling a hole in a block of rock with the drill steel already a certain distance within the rock at the time the noise readings are taken. A maximum of five measurement positions are stipulated at a distance of 1 m from the centre of the rockdrill. Although the requirements of the test code do not model reality and, indeed, are not meant to, the code provides at least for a standardized and reproducible set of conditions that can be applied internationally.

Manufacturers can thus monitor changes in the noise characteristics of their equipment as they endeavour to reduce noise levels, and purchasers of equipment can compare the noise characteristics of one manufacturer's equipment against that of others as one of their decision criteria to be used before purchasing equipment.

However, the concern in this paper is with the noise level likely to be experienced by the operator of the equipment. In such cases, the noise levels to which the drill operator will be exposed are modified by the acoustic properties of the working environment. The absorption coefficient of the surroundings can vary from $\alpha = 0$, where all the incident sound energy is reflected, to $\alpha = 1$, where all the incident sound energy is absorbed. Savich and Wylie[4] illustrate this as shown in Fig. 2.

In the case of pneumatic-powered rock drills, the pressure of the compressed-air supply also has an effect. Fischer[5] determined this as shown in Fig. 3.

Another major influence on the noise level is the spatial volume in which a rockdrill is drilling. This is readily seen from a consideration of various cross-sectional areas of development ends, as shown by Higginson[6] and reproduced in Fig. 4. This influence would also apply to stopes varying in width from, say, 1 to 4 m.

The power of the machine also plays a part. Some indication of this is given by Savich and Wylie[4]. For an air consumption of 1,5 to 8 m^3/min, the noise ranged from 108 to 118 dB(A) and, for an air consumption of 12 to 18 m^3/m, the noise ranged from 116 to 123 dB(A).

Another influence is the length of drill steel exposed from the hole. Atmospheric temperature and pressure will also have a small part to play.

In addition, there is the matter of several machines working simultaneously. Ordinarily speaking, two pure-tone sound sources of equal sound pressure, when com-

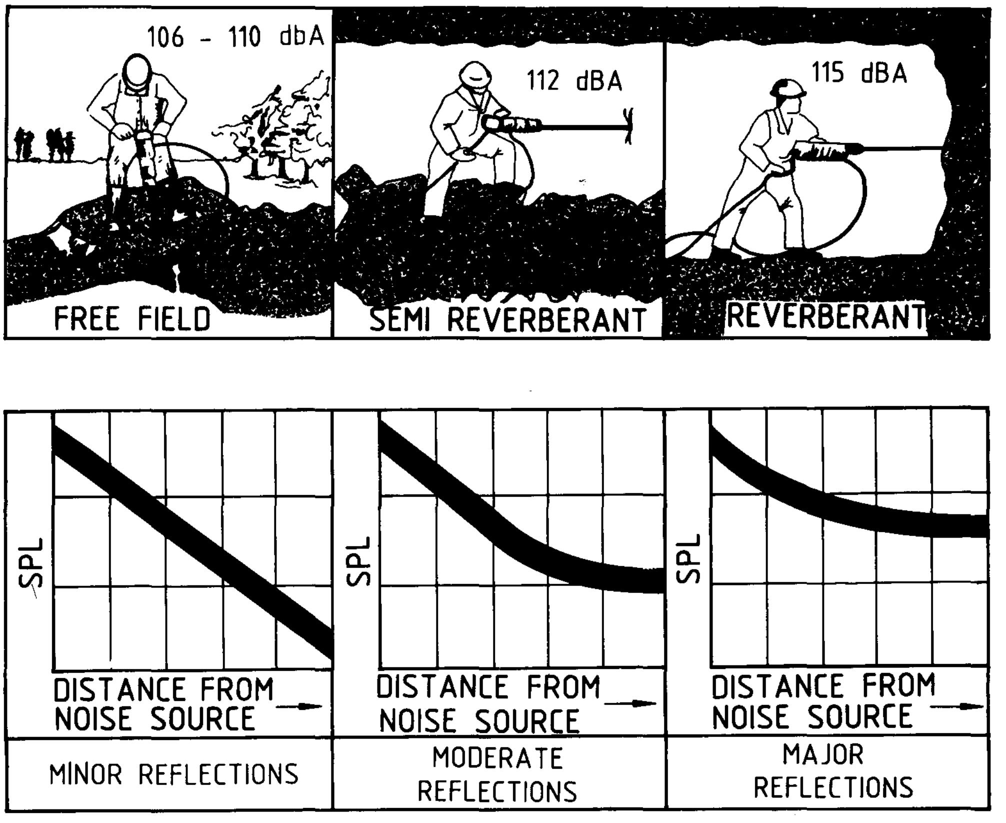

Fig. 2—Effect of the acoustic properties of the environment on noise levels (after Savich and Wylie[4])

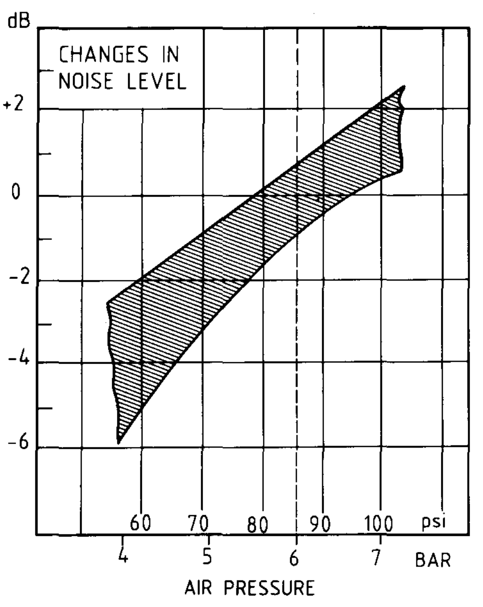

Fig. 3—Influence of air pressure on the noise levels of pneumatic rockdrills (after Fischer[5])

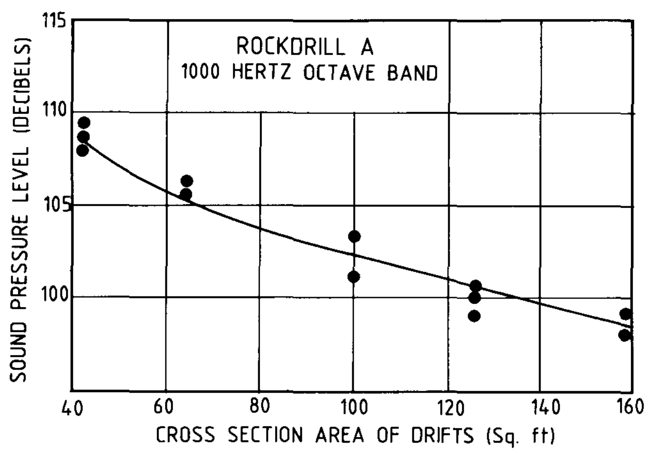

Fig. 4—Influence of the cross-sectional areas of development ends on noise levels (after Higginson[6])

bined, would give an increase of 3 dB in the total level. This is not necessarily the case with multiple rockdrills since the various frequencies can cancel one another out to some extent, resulting in an increase of less than 3 dB.

These comments help to explain Table III, which shows a range of noise levels based on a summary of information extracted from manufacturers' catalogues, published literature, and personal noise-level measurements. The table includes both surface and underground measurements.

Noise from LHD Equipment

In a similar way as for rockdrills, some manufacturers of LHD equipment have been testing the noise characteristics of their equipment.

Table IV shows a range of noise levels based on a summary of information, which, again, was obtained from a variety of sources. The table, which includes both surface and underground measurements, shows that the measurements are influenced by the acoustic properties of the environment in the same way as they were for rockdrills.

In a few instances, some of the equipment was designed and fitted with soundproof cabs. In general, however,

TABLE III

NOISE LEVELS FOR VARIOUS ROCKDRILLS

Type of rockdrill	Penetration index	Weight index	Range of noise level at operator's ear dB(A)
I. Hand-held low-power rockdrills for narrow stopes and development ends			
Pneumatic, unsilenced	100	100	110–120
Pneumatic, simple silenced (exhaust only)	90	110	104–114
Pneumatic extensively silenced (total redesign of machine)	90	110	97–105
Hydraulic	200–300	110	97–110
II. High-power rockdrills mounted on a jumbo or rig for massive stopes and development ends			
Pneumatic, unsilenced			116–123
Pneumatic, unsilenced, but operator in a soundproof cab			86–89*
Pneumatic, extensively silenced (total redesign of machine)			103–111
Hydraulic			102–106

*After Richard[7]

TABLE IV

NOISE LEVELS FOR LHDs

Locality	Noise-level range at the operator's ear, dB(A) Idling	Working, moving, tipping	Full-throttle loading
Surface test			
Various sizes of LHD	90		101
Various sizes of LHD, but operator in soundproof cab (Toro 10)	80		
Underground			
Various sizes of LHD in various environments	82	96–102	106
*Special underground test with various filters**			
Without filter	86,2	100,9	102,6
With filter 1	84,7	97,4	96,9
With filter 2	82,6	96,1	95,1
With filter 2, muffler, and fume diluter	84,3	96,1	96,7

*After Savich and Weglo[13]

such an approach is regarded by manufacturers and mines as unpractical and expensive: unpractical because of the difficulty in maintaining visibility through the windows, and expensive because a cab would give rise to ventilation problems for the operator, which, in turn, would require air-conditioning with its attendant problems of expense and maintenance. It is therefore considered to be more practical and less expensive for operators to wear hearing-protective devices.

Coping with Rockdrill Noise

It can be seen from the results presented in Table III that, irrespective of the standard being considered, a pneumatic low-powered hand-held rockdrill operator is exposed to high noise levels, of the order of 115 dB. He should therefore be exposed only for a duration ranging from, at worst, 28 seconds per day per 40 hour working week for 40 years (the standard used by South Africa) to 15 minutes per day per 40 hour working week for 40 years (the standard used by the MSHA in the USA). Similarly, the operator of a hydraulic high-powered jumbo-mounted rockdrill is exposed to noise levels of the order of 100 dBA, and could work for a duration ranging from, at worst, 15 minutes per day per 40 hour working week for 40 years to 2 hours per day per 40 hour working week for 40 years. Thus, on a daily basis, the operator is being over-exposed to noise.

The problems involve the following:

(a) the extent to which pneumatic and hydraulic rockdrill systems can reasonably be silenced,
(b) the extent to which operators can reasonably be housed in sound-proof cabs,
(c) the extent to which an operator can be exposed to such noise for a shorter period than 40 years, say 5 years, and not suffer hearing impairment,
(d) the extent to which use should be made of already-deaf people as operators, and
(e) the extent to which operators can reasonably wear hearing-protective devices.

Engineering research and development have been undertaken in many parts of the world to address problems (a) and (b) and some improvement is possible. In some countries that have been able to afford it, changes have been implemented. However, there is still a technical problem and no one country has been able to implement reasonable changes to a sufficient extent. Problem (c) is being partially solved in practice because some people are promoted or transferred out of a noisy occupation into a less noisy occupation, or they resign from such work. The problem remains for those that are to continue permanently in a noisy occupation. The idea behind point (d) seems bizarre at first, but not more so than the practice of some US companies who are deliberately employing mentally retarded people for certain work[8].

Personal Protection

Ear protection can be specified where it is not practical or economic to reduce noise levels to meet the acoustic objective without individual ear protection. However, as with the wearing of any protective equipment (such as car safety belts), there is a human reluctance to make full use of what is available.

There are three basic forms of personal protection.

(1) Temporary ear plugs, which are formed from disposable material and have the advantage of being hygienic, easily dispensed, and able to be worn with helmets and spectacles. However, they constitute a recurring cost.
(2) Ear plugs, which are made in different sizes for they must fit tightly to be effective. They are relatively inexpensive and durable, and are not encumbered by helmets and spectacles. They can be uncomfortable when worn for long periods and are difficult to keep clean in a mining environment.

(3) Ear muffs, which are rigid cups designed to completely cover the ears. Each cup has a soft cushion filled with plastic foam or fluid to ensure a good seal between cup and head. The cups are held in place by an adjustable headband when no hard hat is worn, or can be attached as part of the hard hat. In either case, they are relatively heavy and expensive, and may be difficult to wear for long periods in hot, humid, or dusty conditions.

The most important consideration in the design of a hearing protector is its sound attenuation, which depends both on the frequency characteristics of the noise in which it is worn and the quality of the fit. Generally, protectors attenuate noise at high frequencies better than at low frequencies[9].

Thus, it can be seen that a range of suitable devices capable of attenuating noise are available for personal hearing protection. Laboratory tests might show an ability to attenuate 20 to 30 dB, but in practice it is more reasonable to expect an attenuation of 15 to 20 dB because of the possibility that the device may not fit properly (Fig. 5). There is also the problem of educating and motivating workers to wear these devices consistently since they are a nuisance and encumbrance in themselves.

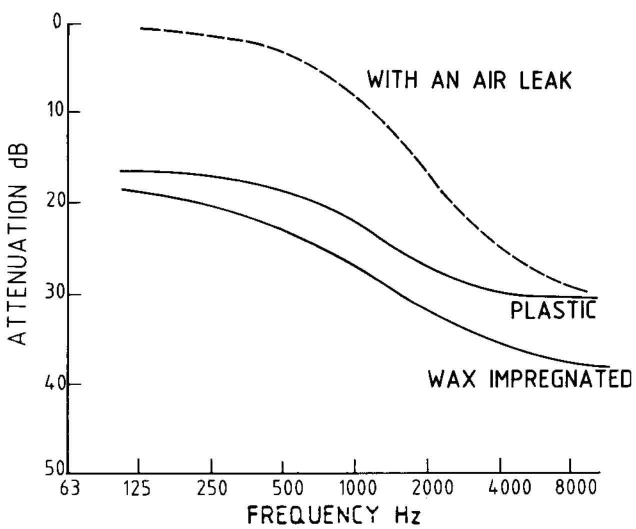

Fig. 5—Attenuation achieved by the wearing of ear plugs

However, if such objections and difficulties could be overcome, the result would be that pneumatic low-powered hand-held rockdrills could be used for 15 minutes to 2 hours a day for a 40-hour working week for 40 years. The hydraulic high-powered jumbo-mounted rockdrill (trackless) could be used for 8 hours and longer per day.

The Noise Benefit of Trackless Mining

From the points of view of the reduction of noise levels, the duration of exposure, and the number of people exposed, trackless mining is an attractive method. The noise levels of trackless-mining equipment are lower than the traditional equipment used. Because of its production capacity, trackless equipment is also able to produce more in a shorter time with fewer people. For example, a wide orebody being mined by traditional methods and equipment might require a complement of 360 people for a production of 35 kt per month. The same orebody being mined with trackless equipment might require only 80 people for the same production. This means that only 80 people would be exposed to a lower noise level for a shorter duration, and these changes all contribute to an overall improvement in the long-term level of hearing ability of the 80 people employed.

These considerations give an idea of the benefit to noise reduction that can be expected from the use of trackless equipment. There are obviously other, more important advantages and disadvantages to be considered, and these, together with the mining circumstances and costs involved, will determine the practices that are implemented.

Noise Standards for South Africa

What South Africa can afford in terms of a noise standard can be summed up with the help of Fig. 6, which is based on an approach towards environmental quality discussed by Fugel and Rabie[10]. Lower noise levels, lower dust levels, lower water-pollution levels, lower levels of toxic chemicals, lower gas levels, and lower accident statistics can all be regarded as components of environmental purity.

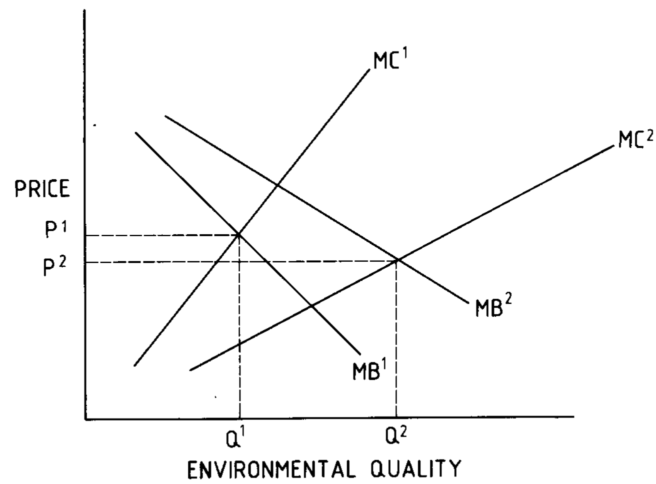

Fig. 6—Optimum level of environmental quality for two societies

In a comparison of the optimum level of environmental quality for Society 1 and Society 2 (Fig. 6), it can be seen that Society 2 has a higher level of environmental quality ($Q^2 > Q^1$) at a lower cost ($P^2 < P^1$). The optimum level of environmental quality depends on the value a society puts on environmental purity and on the state of technology existing in that society. For Society 1, the costs (MC^1) of achieving a given level of environmental quality are relatively high owing to poor technology, and the benefits (MB^1) from a given level of environmental quality are relatively low owing to greater concern for more pressing needs. Society 2 is able to achieve higher levels of environmental quality at lower cost (MC^2) because of improved technology, and to realize greater benefits (MB^2) owing to the higher valuation that it places on environmental purity.

Society 1 could, for example, be thought of as South Africa and Society 2 as the USA. In the case of noise, South Africa has set a higher standard of environmental quality than has the USA. However, South Africa has a lower overall state of technology than the USA, and the benefits that South Africa can derive from a given level of environmental quality are relatively low owing to a greater concern for more pressing needs.

If one accepts the general principle embodied in the graph of Fig. 6, one must conclude that South Africa is perhaps over-concentrating on its noise standard at the expense of achieving other more pressing needs. Support for this statement is gained through a consideration of the experience of the USA and Great Britain.

> 'In the USA the original proposed OSHA workplace noise standards of 85 dB would have cost industry between $18 billion and $31 billion (in 1976 dollars) to meet. The compromise standards that OSHA finally worked out will allow 90 dB, but will still cost industry about $250 million'[11].

> 'In Great Britain when legislation of this kind is about to be enacted there is always an outcry from industry that the measures proposed will adversely affect their business. In this case, what arguments could be made against the proposed regulations? First, perhaps, is the fact that additional investment will be needed at the workplace to meet the regulations, which will naturally increase costs and could lead to a lack of competitiveness with overseas industry . . . Mr Harris, a member of the Council of the British Society of Audiology has said that the decision to adopt 90 dB(A) as an action level undoubtedly reflects on Britain's present economic position and added that the proposed legislation is a very welcome step forward'[12].

Conclusions

A reduction in noise levels and duration of exposure, and hence a reduction in noise-induced hearing impairment, is an admirable objective. The implementation of trackless mining is fortuitously a move in this direction. Trackless mining, being a newer state of technology has a production capability that requires far fewer people than do traditional methods of mining, and this minimizes the number of people exposed to occupational noise in mining. It is pertinent to ask what alternative employment is available for those now without a mining occupation. A correct balance must be struck between safety and health, occupational security, and the price that society must pay for its raw materials. It is only society at large that can take this decision, but people in the mining industry must ensure that they participate in the debate.

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Book review

• *Kinetics and mass transport in silicate and oxide systems,* edited by G.E. Murch, R. Freer, and P.F. Dennis. Materials science forum, vol. 7, 1986.

Reviewer: W.H. van Niekerk

This volume contains the proceedings of a conference held in London in September 1984. The aim of the conference was to address interdisciplinary but related problems in kinetics and mass transfer. The subject matter is divided into five categories: Characterization, Kinetics, Modelling Studies, Mass Transport, and Industrial Topics, as well as an introductory paper that provides an overview of mass transport in oxides.

The characterization section discusses recent advances in characterization studies, such as high-resolution powder neutron diffraction.

The kinetics section, containing the bulk of the papers, covers various topics ranging from aluminium and silicon ordering in minerals to the reaction mechanism between magnesium oxide and chromite at 1530 °C.

Four papers are included under modelling studies, again covering rather diverse topics, including model intercalation studies and computer simulation studies of silicates.

New techniques for the study of mass transport in oxides are the subject of the introductory paper in the mass transport section, which also includes papers on various diffusion studies, for example cation diffusion in natural silicate melts.

The last section, containing four papers, is introduced by a paper indicating how studies of mass transport can be applied to industrial problems.

On the whole, the organizers succeeded in attracting interesting papers for the various subjects, all of them related to silicate and oxide systems in one way or another. The book clearly shows that many fundamental problems are interrelated in the different disciplines. Consequently, it makes stimulating reading, and may provide the reader with a new approach to a difficult problem.

The book will be of value to nearly all who are interested in kinetics and mass transfer, but especially to material scientists, chemists, ceramicists, and engineers working in research environments.