A novel method for the underground disinfection of mine water by *in situ* chlorine generation

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SYNOPSIS

Although a regulation is in force that all water used underground shall be free of bacterial contamination, in practice it is often very difficult to accomplish this. The standard method of disinfection in South African mines is treatment with calcium hypochlorite, although liquid sodium hypochlorite is used at a few sites. Primarily because the process depends on human control for the addition of the hypochlorite and the regulation of its flow, it is frequently found difficult to disinfect mine water adequately and continuously.

In many marine environments, chlorine generated by the electrolysis of seawater in its passage through an electric cell is used for disinfection. The generation procedure is continuous and needs no human control except for occasional checking of the equipment. This paper describes the successful implementation of the process, suitably modified, at four underground sites. After severe scaling problems had been overcome, a procedure resulted that chlorinates considerably more effectively than the previous system (dosing with calcium hypochlorite), and that has a lower amortized operating cost.

SAMEVATTING

Hoewel daar 'n regulasie van krag is dat alle water wat ondergronds gebruik word vry van kontaminasie deur bakterieë moet wees, is dit dikwels baie moeilik om dit in die praktyk te bewerkstellig. Die standaardontsmettingsmetode in Suid-Afrikaanse myne is behandeling met kalsiumhipochloriet, hoewel vloeibare natriumhipochloriet op 'n paar plekke gebruik word. Daar word dikwels gevind dat dit moeilik is om mynwater toereikend en voortdurend te ontsmet, hoofsaaklik omdat die proses van menslike beheer afhanklik is vir die byvoeging van die hipochloriet en die regulering van die vloei daarvan.

Chloor wat ontwikkel word deur die elektrolise van seewater in sy gang deur 'n elektriese sel, word in baie seeomgewings vir ontsmetting gebruik. Die ontwikkelingsprosedure is ononderbroke en het, afgesien van die nagaan van toerusting nou en dan, geen menslike beheer nodig nie. Hierdie referaat beskryf die geslaagde toepassing van die proses, met gepaste wysigings, op vier ondergrondse plekke. Nadat ernstige probleme in verband met skaalvorming oorkom is, is daar 'n prosedure ontwikkel wat heelwat meer doeltreffend chloreer as die vorige stelstel (dosering met kalsiumhipochloriet) en waarvan die geamortiseerde bedryfskoste laer is.

Introduction

Mine service water is available in all South African mines where drilling is undertaken, i.e. in virtually all underground mines. This water is normally unpalatable because it contains high concentrations of dissolved solids, with sometimes excess acidity or alkalinity, diesel fuel spillages, or other mining debris. It may have an unpleasant odour.

It is standard procedure to place drinking-water points as near the working faces as is practical. At the many sites where the mining process includes refrigeration, the potable water, as well as the service water, is chilled. At all sites, mining personnel are instructed to drink the potable water, and not the service water. However, the injunction is often disobeyed. For this reason, as well as for reasons of general hygiene, there are regulations that all the service water shall be disinfected to potable water standards, i.e. the water shall be free of faecal *coli* (and have low presumptive and total organism counts).

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It has been shown in the past sixteen years, particularly in warmer climates [1-3], that there are other disease-producing pathogenic organisms in the service water (salmonella strains, *entamoeba hystolytica*, etc.), which are more resistant to chlorination than *E.coli*. Hence, the absence of *E.coli* after chlorination is not always an indication that all potentially harmful pathogens have been eliminated. However, the current situation has been summarized by J.A. Thomson[3]:

'Never-the-less the indicator organism accepted universally is *E.coli* because of the enormous numbers found in the excreta of man, other mammals and birds.'

Experiments have been undertaken on the use of ultraviolet light or other procedures for the disinfection of water underground, but in practice chlorination is used virtually exclusively. Although the use of chlorine gas is permitted, and it has actually been used in the past on a limited basis, gaseous chlorine is invariably considered to be so toxic and hazardous that chlorine cylinders are not taken underground. Solid or liquid chemicals that are easier to transport and safer to handle are used instead. These, on dissolving in water produce, like chlorine gas, hypochlorous acid (HOCl) which has powerful disinfecting and bactericidal properties. Several chemicals such as sodium hypochlorite, chloride-of-lime, lithium hypochlorite, and granular calcium hypochlorite (70 per cent available chlorine) can be utilized. The first is applied at one or two sites; elsewhere the last is used exclusively.

Although widely employed, calcium hypochlorite is not the ideal additive for use underground. One of the main disadvantages is the difficulty of feeding the solid, or a relatively concentrated solution of it, at a constant dosage rate. Apart from chlorine gas, it is the cheapest form of available chlorine but it is still expensive to use. The hypochlorite increases the pH value of the service water, which in practice decreases the disinfecting activity of the hypochlorous acid solution formed; additional calcium is added to the water, increasing its scaling tendencies, which are probably already high.

Electric Chlorine Generators

For a considerable number of years, kits for the *in situ* electrical generation of chlorine water (in the form of sodium hypochlorite) have been available commercially. These units are not practical for industrial use since the carbon electrodes have an active life of only about three to six months.

Early in 1976 it was learnt that industrial units with platinized titanium electrodes, guaranteed for a minimum life of five years, were being manufactured to produce chlorine from seawater. These chlorinators consist essentially of a transformer that supplies direct current to platinized titanium anodes and titanium cathodes arranged in the form of tubes. The chlorine is generated as sodium hypochlorite during a 'once through' passage of the seawater through the tube cell.

The system appeared to have considerable potential if it could be adapted for underground use. It was realized that, in these circumstances, a manufactured brine solution would have to be recirculated relatively rapidly through the chlorinator while a slight, controlled discharge from the circuit into the mine service was allowed.

The assembly has sophisticated controls to prevent overheating, and has cutouts for excess current and low fluid flow, a leak detector, and automatic reset and level-control switches. Its power supply is designed to convert

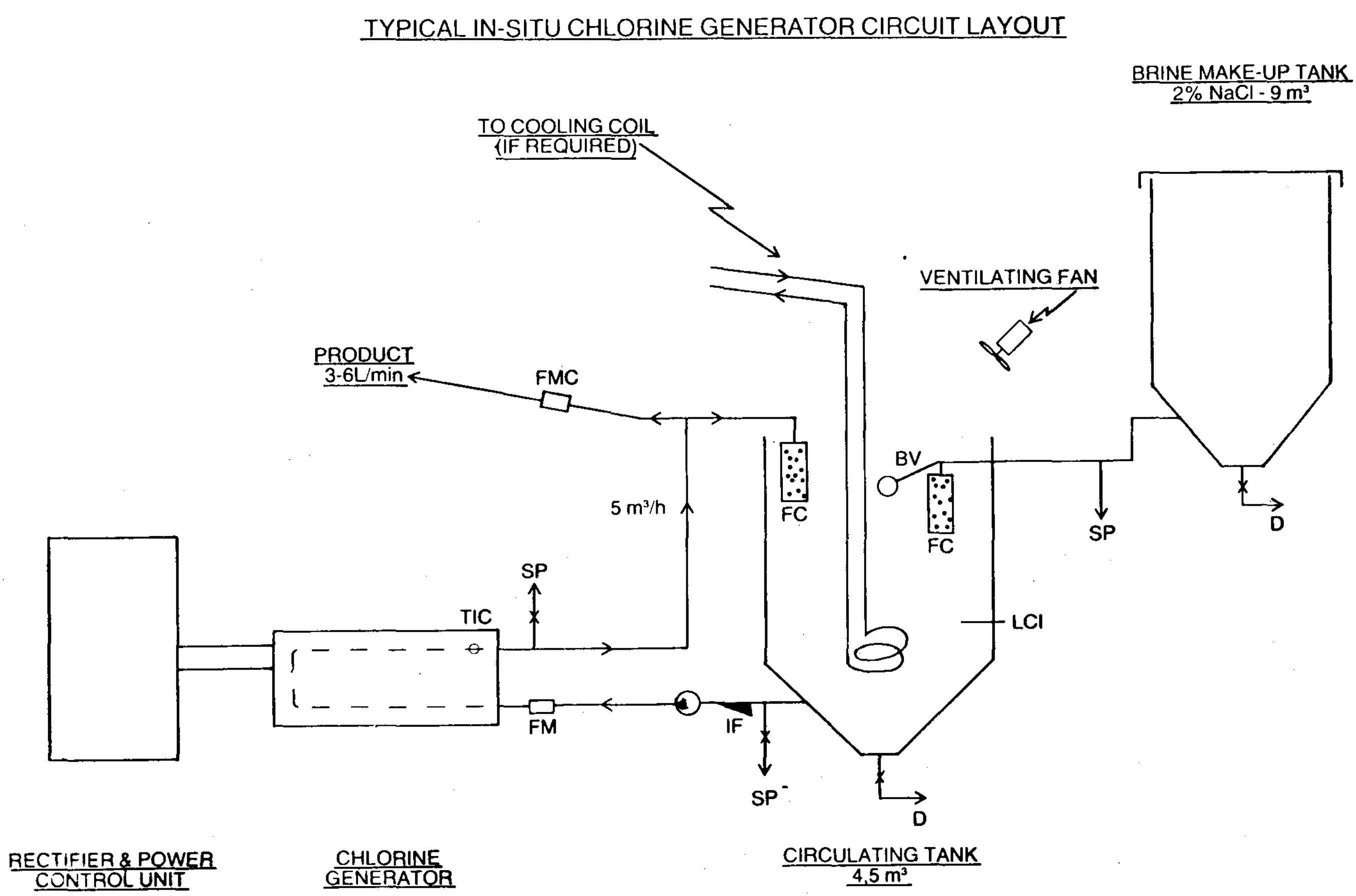

Fig. 1 — A typical circuit for an *in situ* chlorine generator.

BV	**Ball valve (or LCI high)**		
D	**Dirt-drain valve**	**IF**	**In-line filter**
FC	**Filter-cloth bag**	**LCI**	**Low-level controller/indicator**
FM	**Flow meter**	**SP**	**Sampling point**
FMC	**Metering pump/orifice plate or flow meter**	**TIC**	**Temperature Controller**

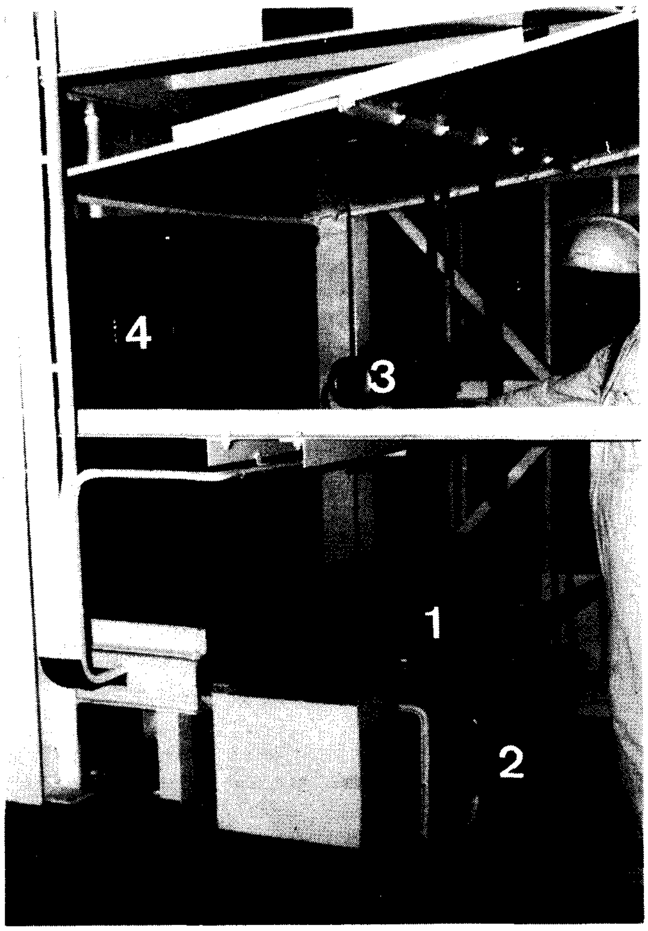

Fig. 2 — The chlorine generator at Western Holdings
1. Housing for 2 generating cells
2. Main circulating pump
3. Bleed pump
4. Rear view of electrical transformer and control unit

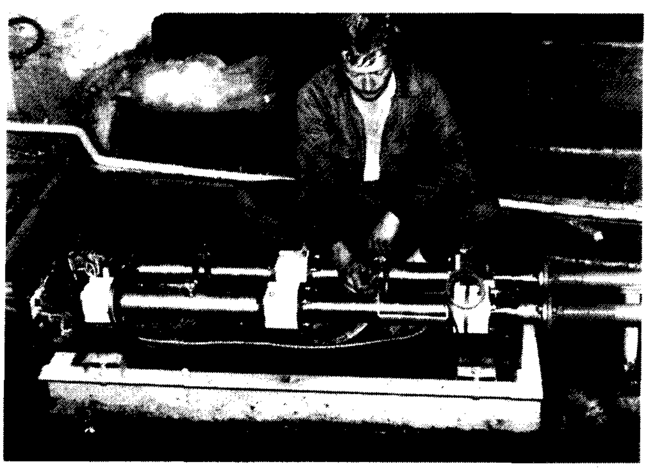

Fig. 3 — A view of the chlorine-generating cells.

a standard three-phase 50/60 Hz supply into the high-current, low-voltage d.c. power required by the cells. The main components of the power supply required to perform this function are as follows: a step-down transformer, a saturable reactor assembly, a variable controller, an auxilliary transformer, and a rectifier assembly. These components are housed in a single lockable power-supply enclosure.

The electrolysis of salt water releases hydrogen at the rate of 0,25 m^3/kg of sodium hypochlorite generated. The hydrogen remains entrapped in the pipework and is released to the atmosphere over the recycle tank. Measures should be taken to provide continuous forced-draught ventilation at the location to sweep away the hydrogen. This draught assists in cooling the circulating brine.

To ensure that all, or as much as possible, of the underground service water is chlorinated, the site for the installation must be carefully chosen. In most instances, an appropriate site is either into, or at the outlet from, the main dam feeding the machine water to the working levels below.

The manufacturers of the unit were enthusiastic about the system's potential for underground chlorination, and they provided a 0,9 kg/h chlorine unit for underground testing. The unit provided was run with the co-operation of the Engineering Management at Western Deep Levels after the necessary brine-circulating system had been added. Because of problems not associated with the chlorinator, the operation was intermittent, but the results appeared so successful that four additional units were purchased for advance testing, one each by Western Holdings, President Brand, Vaal Reefs, and Western Deep Levels.

The original test was undertaken on an assembly designed for marine use, and during the test it became apparent that, for underground installation, the design would need to be modified to ensure better waterproofing and more sophisticated controls. These modifications were incorporated in the four additional units.

As already stated, the initial test operation was intermittent. When the second-generation of four chlorinators commenced operation, more or less continuously, it became apparent that all the difficulties had not been solved, and that higher-than-desirable fluid circuit temperatures and potential scaling problems still persisted. Apart from these problems, which are discussed below, the chlorinators have proved singularly free from mechanical and electrical operational defects in an aggregate of over ninety months of operation.

A representative circulating and dosing flowsheet for a chlorine generator is shown in Fig. 1, and Figs. 2 and 3 are photographs of a typical installation. The horizontal tubes in Fig. 3 are the two chlorine-generating cells. Fig.2 is a general view showing the major components of the installation.

Problems during Commisioning

Scaling Tendency

Although many chlorinators have been installed worldwide, almost all of these operate on a 'once through' system using seawater. In this mode of operation, scaling of the chlorine-generating cell virtually does not occur.

The chlorine-generation electrolysis produces sodium hypochlorite as the main product, but a slight excess of caustic soda and a little sodium chlorate are also generated. The excess caustic soda produced increased the pH value of the 3 per cent brine used in the first three permanent installations to a pH value of over 9, and raised the Langelier index of the brine circuit to the highly scaling potential of at least plus 3,0.

During the initial period of operation at each mine, some calcium carbonate scale formed in all the cells. Except at one site, the scaling was discovered before overheating occurred. A simply daily addition of 200 ml of a polyacrylate scale inhibitor and dispersant to the circulating system, plus the use of a ventilation type of bag filter, has overcome the scaling problem. The bag is used to remove the small quantity of inert matter present in the solid salt that is used to make up the brine, as well as any calcium carbonate sludge that may form.

Operating Temperature

According to the manufacturer's specification, each pair of cells is capable of producing 0,9 kg/h of chlorine as sodium hypochlorite. It was found in practice that the cells were generating only 60 to 65 per cent of the specified output. Investigation and analysis confirmed that the units were, in fact, generating the hypochlorite but, during the recycling, this was being 're-oxidized' to sodium chlorate. The latter is a strong oxidizing agent, and is used for this purpose in, for example, fireworks, but it has no disinfecting action. Further, the higher the operating temperature, the greater the tendency for the hypochlorite to be converted to chlorate. Upon being informed of the fact that the hypochlorite output was lower than expected, the manufacturer undertook laboratory tests, which revealed that the following was occurring with the Anglo American recirculating systems.

1. The rated efficiency of 100 per cent hypochlorite could not be obtained because, during the passage of the brine through the cell, some chlorate is formed, primarily from the hypochlorite. Each recycle of the brine caused more hypochlorite to form chlorate. It follows that a reduction in the number of cycles should increase the efficiency of hypochlorite production.
2. Approximately 2 per cent of the hypochlorite-generating efficiency was lost per 1°C increase in temperature above 30°C.
3. A reduction in the concentration of the circulating brine from 3 per cent to 2 per cent did not change the rate of hypochlorite production.

From the third finding, it follows that, if the brine concentration is reduced to 2 per cent and a portion of the brine is bled from the circuit at 1,5 times the previous rate, the daily consumption of salt will remain unchanged. However, the number of (re-) cycles of the brine will decrease by one-third. It was estimated that this change would increase the chlorine produced by approximately 25 per cent, i.e. at an operating temperature of 30°C from, say, 60 per cent efficiency to 75 per cent of the rated (once-through) capacity of 0,9 kg/h.

The circuits of the mines that were operating chlorinators were therefore examined individually, and the mines were advised to weaken the brine solution to 2 per cent and to increase the circuit bleed rates. The alteration has been undertaken at Vaal Reefs and Western Deep Levels. At these sites, the operating efficiency of the chlorine 'generation' has been raised to over 80 per cent of the rated value.

In marine use, i.e. with seawater passing through the cells in a single passage, the temperature of the brine virtually never exceeds 25°C. At the underground installation sites chosen so far, the ambient water temperatures are around 30°C. When the unit operates in a recirculation mode, the resistivity of the solution causes a further increase in temperature until the rise becomes balanced by the natural heat losses from the circuit. In view of the loss in operating efficiency mentioned earlier, it becomes advisable at water temperatures above 30°C to cool the system by means of an external source if the temperature exceeds, say, 35°C. A supply of cool ventilation air around the unit has proved to be adequate at the four Anglo American installations, but, if installed in a very hot site, a cooling coil in the brine reservoir through which chilled mine water is passed may have to be employed for supplementary cooling.

Materials of Construction

Difficulties were experienced with some of the original materials of construction. Suitable materials are as follows:

for the brine-supply system
rubber-lined mild steel, polyethylene, polyvinyl chloride

for the brine-circulating system
rubber-lined mild steel, chlorinated polyvinyl chloride, polypropylene, polyvinyl/chloride (a limited life only).

Results and Discussion

Table I gives, a comparison for the four sites of the bacteriological results when the water was dosed with calcium hypochlorite and when *in situ* chlorine generation was used.

At first sight, the values in Table I do not appear markedly different when the *in situ* generator was used from when calcium hypochlorite was employed but, as the summary at the bottom of the table shows, the presence of faecal *coli*, which is the ultimate criterion, occurred on approximately half the 25 occasions when calcium hypochlorite was used and in only two instances out of 32 (and one of these was very small) when the *in situ* generator was in operation.

TABLE I
BACTERIOLOGICAL REPORTS ON MINE SERVICE WATER

Date		Level	Total count per ml	Presumptive coliforms per 100 ml	Faecal coliforms per 100 ml
			Site 1		
Using calcium hypochlorite					
Sept.	15th 1978	36	Innumerable	600	Present
		38	3	Nil	Absent
	22nd	36	3	Nil	Absent
		38	Spread	Nil	Absent
	29th	36	23	Nil	Absent
		38	27	Nil	Absent
Oct.	6th 1978	36	Spread	1 800	Present
		38	Innumerable	1 800	Present
Using the *in situ* generator					
Dec.	30th 1979	36	Innumerable	2	Absent
		38	Innumerable	Nil	Absent
Jan.	14th 1980	36	23	Nil	Absent
		38	6	Nil	Absent
	25th	36	20	8	Absent
		38	3	11	Absent
Feb.	4th 1980	36	Innumberable	Nil	Absent
		38	Innumberable	5	Absent
			Site 2		
Mainly using the *in situ* generator					
June	6th 1979	42	1	Nil	Absent
	16th	42	Innumerable	50	Absent
	29th	42	Spread	2	Absent
July	6th 1979	42	Innumerable	1 800+	Present*
	15th	42	Innumerable	25	Absent
	20th	42	Spread	2	Absent
	27th	42	8	0	Absent
Aug.	10th 1979	42	3	0	Absent
	17th	42	Innumerable	1 800	Present*
	24th	42	Innumerable	0	Absent
	31st	42	3	2	Absent
Sept.	7th 1979	42	4	0	Absent
	17th	42	4	0	Absent
Nov.	9th 1979	42	2	0	Absent
	21st	42	Innumerable	600	Absent
Dec.	10th 1979	42	Innumerable	9	Absent*
	21st	42	Innumerable	1 800+	Absent*
Jan.	14th 1980	42	Innumerable	0	Absent*
	18th	42	Spread	0	Absent*

*Chlorinator out of use for tank repairs and calcium hypochlorite being used.

Date		Level	Total count per ml	Presumptive coliforms per 100 ml	Faecal coliforms per 100 ml
			Site 3		
Using calcium hypochlorite					
March	7th 1980	61	Innumerable	2 400	Present
	14th	61	Innumerable	4	Absent
	21st	61	Innumerable	0	Absent
April	4th	61	Innumerable	2 400	Present
	11th	61	Innumerable	2 400	Present
	18th	61	Innumerable	43	Absent
	25th	61	40	Nil	Absent
June	20th	61	Innumerable	2 400	Present
Using the *in situ* generator					
July	11th 1980	61	Innumerable	93	Absent
	17th	61	Innumerable	10	Absent
	25th	61	92	Nil	Absent
Aug.	1st	61	43	2 400	Present
	8th	61	Innumerable	Nil	Absent
	13th	61	Innumerable	Nil	Absent
Sept.	1st	61	1	Nil	Absent
			Site 4		
Using calcium hypochlorite					
Jan.	1979	100	> 1 000	600	250
March	1979	100	> 1 000	1 600	600
Nov.	1979	100	> 1 000	900	900
Using the *in situ* generator					
April	1979	100	> 1 000	5	2
May	1979	100	> 1 000	8	Absent
June	1979	100	> 1 000	2	Absent
June	1980	100	> 1 000	0	Absent

Summary

Defective results when calcium hypochlorite was used, 12 out of 25; when the *in situ* generator was used, 2 out of 32, 1 being only just defective.

Site 1

Table I shows that no faecal *coli* were reported when the chlorinator was in use, but, when granular hypochlorite was used, they were sometimes present. Site I has a relatively intricate distribution circuit of service water (i.e., the passage of water before it drains back to the settlers). Even when relatively larger doses of hypochlorite were used, faecal *coli* were frequently reported. The improvement resulting from the use of *in situ* generation becomes particularly meaningful when the reduction in operating cost, shown in Table II, is considered; less than R22 per day for *in situ* chlorination achieved better results than R90 per day for dosage with granular hypochlorite.

Site 2

Table I shows that faecal *coli* were sometimes present when hypochlorite was employed, but never when the *in situ* chlorinator was in use. As shown in Table II, the generator reduced the operating cost from R33 to less than R22 per day.

Site 3

Table I shows that on only one occasion in seven were faecal *coli* present when the *in situ* generator was operating, but on about 50 per cent of the occasions when calcium hypochlorite was used. The cost saving resulting from the generator was considerable: the cost fell from R180 to less than R19 per day. The main disinfection problem at this mine was that it had been using Anfex explosive, 1 kg of which consumes over 9 kg of chlorine. This situation is thought to have contributed largely to the high demand for hypochlorite at the site. At site 3 the circulation of service water is extensive and, although it is considered that the chlorinator installed provided sufficient disinfection, it is proposed to increase the size of the unit.

Site 4

Biological analyses are undertaken monthly at this mine. The vastly improved results when the *in situ* generator was used are clearly shown in Table I. The cost saving (Table II) is also significant.

Conclusions

It is clear from the examples cited above that the underground chlorine generators give far superior results to the procedure previously followed, in which hypochlorite granules were either added directly to the mine service water or they were pumped slowly in solution. The main reason for this improvement is that the disinfecting chlorine solution from the generators is applied both automatically and continuously. With the generators, human control of the dosing procedure is completely eliminated; provided that the salt solution is made up daily and the simple schedule for checking the equipment is observed.

The financial savings of the generator system are significant and, where large quantities of hypochlorite had previously to be used, the savings will pay for the cost of the installation in a short period.

The *in situ* generators have proved singularly free from mechanical and electrical defects. However, despite their reliability, they and their installations constitute sophisticated equipment, and it must be borne in mind that, for trouble-free operation, they need adequate but simple routine inspections and maintenance. As with a compressor or winding engine, each unit should have its own log book in which a few simple parameters, such as voltage, amperage, temperature, flowrate of circulating brine, and discharge rate, should be recorded daily.

Acknowledgement

The authors thank the management of the Anglo American Research Laboratories for permission to publish this paper.

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TABLE II
DAILY OPERATING COSTS FOR WATER DISINFECTION

Site no.	Using the *in situ* generator				Using calcium hypochlorite		Saving when using *in situ* generator, R
	Power R	Salt R	Daily amortization, R	Total R	Consumption kg	Cost R	
1	3,00	10,50	8,10	21,60	50,0	90,00*	68,40
2	2,25	10,50	8,10	20,85	18,3	33,00	12,15
3	2,90	7,65	8,10	18,65	100,0	180,00*	161,35
4	1,90	6,50	8,10	16,50	15,0	27,00	10,50

* Explosive in use at the time was Anfex, which consumes large quantities of chlorine.