The effect of microwave radiation on the processing of Palabora copper ore

by S.W. Kingman, W. Vorster and N.A. Rowson*

SYNOPSIS

The effect of microwave radiation on the processing of Palabora open pit ore has been investigated. Significant reductions in Bond work index are demonstrated for microwave treated samples. Reductions in work index were found to be sensitive to applied power level and method of application. After single stage magnetic separation tests, improvements in recovery of FeO were noted. However, these were curtailed by oxidation of the magnetite species as a result of continued heating. The effects of microwave radiation upon the recovery of copper after froth flotation were also quantified. Small initial increases in recovery of copper were noted after microwave treatment. However, with prolonged exposure, recovery was found to decrease. Overall recovery of copper was not affected except for samples treated for extended duration. The influence of microwave treatment upon the conventional Palabora grinding circuit has been quantified with the use of USIMPAC software. Conclusions are made regarding the economics of microwave treatment for this ore.

Keywords : Microwave; Grinding; Magnetic Separation; Flotation; Economic Analysis

Introduction

Microwaves may be defined as that part of the electromagnetic spectrum that lies between the infra red and radio frequency with wavelengths between 1 m and 1 mm. When microwave energy is applied to a material, the contained material dipoles align and flip around, at the frequency of the applied energy. Thus, the material heats when the stored internal energy is converted to heat energy, due to friction. This in situ mode of energy conversion has the attraction of being selective to individual mineral phases within a mass (Kelly and Rowson, 1995). Conventional heating has the disadvantage that the total mass of material is heated and the radiation is absorbed into the material by conduction. Overheating and also wasteful heating of insulators can occur. These problems are alleviated with microwave radiation which selectively heats individual phases within a material lattice, causing differential expansion at grain boundaries (Mingos, 1991). Selective heating within mineral lattices has distinct process advantages as it can promote intergranular fracture which reduces required grinding energy and also gives rise to increased liberation of individual mineral grains.

Various factors influence the dielectric properties of a material (or the ability of a material to heat). These include the frequency of the applied field, the temperature of the material and material physical properties.

Initial research into the microwave treatment of minerals commenced in the late 1970s when a U.S. patent for the desulphurization of coal was registered (Zavitsanos, 1978). In 1984 the first extensive study into the effects of microwave radiation on minerals was published (Chen et al. 1984). This paper was qualitative in nature and concluded that most silicates, carbonates and sulphates were transparent to microwave radiation; however, most sulphides, arsenides, sulphosalts and sulphoarsenides heated strongly, emitting fumes and fusing. This initial study was extended in 1988 when a detailed quantitative study into the microwave heating characteristics of minerals was published (Walkiewicz et al. 1988). Mineral samples of 25g were irradiated within a 1kW, 2.45GHz source and final temperature and rates of heating were determined, as shown in Table I.

Another important observation made during this research was that rapid heating of ore minerals in a non heating gangue generated thermal stresses that could cause weaknesses in the mineral matrix. This observation has been extended in recent work (Kingman and Rowson, 1998) where significant reductions of up to 90% of the work index were reported for microwave treated massive Norwegian ilmenite ore in conjunction with increases in concentrate grade and valuable mineral recovery.

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Table I

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Chemical Composition</th>
<th>Max Temp Achieved (°C)</th>
<th>Time (min)</th>
<th>Energy Input (kWh/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chalcopyrite</td>
<td>CuFeS2</td>
<td>920</td>
<td>1</td>
<td>667</td>
</tr>
<tr>
<td>Galena</td>
<td>PbS</td>
<td>956</td>
<td>7</td>
<td>4667</td>
</tr>
<tr>
<td>Magnetite</td>
<td>Fe3O4</td>
<td>1258</td>
<td>2.75</td>
<td>1833</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>KAlSiO3O8</td>
<td>67</td>
<td>6</td>
<td>4000</td>
</tr>
<tr>
<td>Pyrite</td>
<td>FeS2</td>
<td>1019</td>
<td>6.75</td>
<td>4500</td>
</tr>
<tr>
<td>Quartz</td>
<td>SiO2</td>
<td>79</td>
<td>7</td>
<td>4667</td>
</tr>
<tr>
<td>Sphalerite</td>
<td>ZnS</td>
<td>88</td>
<td>7</td>
<td>4667</td>
</tr>
</tbody>
</table>

Palabora Process Description

Palabora is situated in the north eastern part of South Africa, in close proximity to the Kruger National Park. The Palabora igneous complex can be described as a “figure of eight” layout, approximately 8 kilometres from north to south and 3.2 kilometres from east to west. Copper ore has been mined in the area for many hundreds of years (PMC. Ltd, 1998), although mining did not start commercially until 1956, when a joint venture between Rio Tinto and Newmont Mining Company formed The Palabora Mining Company (PMC).

The ore from Palabora consists primarily of magnetite, carbonate, dolomite, quartz and phoskorite. Copper bearing minerals include chalcopyrite, bornite, cubanite, valleriite, chalcocite, malachite and cuprite. Gold and silver are also recovered. Baddeleyite and uranothorite are important secondary minerals.

Approximately 80 000 tonnes of ore are processed daily, 26 000 tonnes being milled in the autogenous circuit and the balance in the conventional circuit. The primary crushers crush the ore to 100%, passing 180 mm, which is fed directly to the autogenous mills, which mill to 80% passing 300 µm. In the conventional milling circuit the primary crushing product passes through secondary and tertiary crushers before being fed to the rod and ball mills, with the final product being 80% passing 300 µm.

The products from the two milling circuits are then fed to the flotation banks, producing a copper concentrate and tailings. The tailings then undergo magnetic separation to separate the magnetite and heavy minerals (mainly U and Zr). The magnetite is stored on stockpiles or sold for use in dense media separation.

Experimental Procedure

Determination of the Effect of Microwave Radiation on Grindability

The effect of microwave radiation upon the grindability of Palabora ore was quantified by the comparative Berry and Bruce method (Berry and Bruce, 1966). This method requires the use of an ore of known grindability. The reference ore is ground for a certain length of time and the power consumption recorded. If an identical weight of test ore is ground for the same time period then the power consumption will be equal to that of the reference ore. Then if \( r \) is the reference ore and \( r \) the ore under test, from Bonds Equation 1

\[
W = \frac{10W_i}{\sqrt{P}} \pm \frac{10W_i}{\sqrt{F}}.
\]

Where \( W_i \) = Bond work index, \( P = 80\% \) passing size of product, \( F = 80\% \) passing size of feed, \( W \) =work input per short ton, it follows:

\[
W_r = W_t = \left( \frac{10}{\sqrt{P_t}} \pm \frac{10}{\sqrt{F_t}} \right) = W_i \left( \frac{10}{\sqrt{P_t}} \pm \frac{10}{\sqrt{F_t}} \right).
\]

Therefore,

\[
W_{it} = \left( \frac{10}{\sqrt{P_t}} \pm \frac{10}{\sqrt{F_t}} \right) \left( \frac{10}{\sqrt{P_r}} \pm \frac{10}{\sqrt{F_r}} \right).
\]

This method has been shown to give accurate values for Bond work index for various ores (Yep et al. 1982). Comparative grinding tests were conducted on representative 1kg samples of ore. Each sample had an identical size distribution. Two microwave heaters were used for the experimental program. This was done to assess the influence of applied power level and microwave application method upon the grindability. The first microwave used was a variable power 2.6kW, 2.45GHz multimode heater. Samples were treated at both 1.3kW and 2.6kW. The second microwave used was a 1.5kW, 2.45GHz monomode heater and samples were treated only at 1.5kW. A multimode cavity is one where the electric field pattern produces successive reflections of the applied wave on the interior cavity of the system. Monomode applicators direct the electric field pattern straight at the sample and are often used for cylindrical products which are located in the centre of the waveguide. In the second microwave unit a nitrogen atmosphere was used to inhibit oxidation of the ore samples.

To quantify changes in grindability a steel rod mill with dimensions 160 mm x 280 mm, containing five rods with dimensions 25 mm x 265 mm, was used. Grinding was continued for 5 minutes at 90rpm. After the required grinding period, the 80% passing size of the ground product was determined by sieve analysis. Samples were irradiated for times varying between 10 and 240 seconds.

Longer exposure times were used for material treated at 1.3 and 2.6kW to ascertain any effects of excessive microwave heating. Shorter times were used for the 1.5kW treatment to reduce any likelihood of sample oxidation.

Determination of the Effect of Microwave Radiation on Flotation

The flotation flow sheet used at PMC, Ltd is complex. It consists of 8 separate, parallel circuits. Sections 1 to 6 receive feed from the conventional milling circuit while sections 7 and 8 receive their feed from the autogenous mills.

Due to the difficulties involved in accurately simulating a flotation system on laboratory scale, only the initial rougher and scavenger cells have been simulated. This allows for a detailed analysis of the flotation properties of the microwave treated ore.

Flotation tests were carried out on samples treated for times of between 10 and 300 seconds. Flotation tests were conducted in a standard Denver laboratory flotation cell, the
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feed for all tests being 80% passing 300µm as is plant practice. A 3-litre glass cell was used in all cases with a constant impeller speed of 2000 rpm. 25g/t Sodium IsoButyl Xanthate (SIBX) was used as collector and 35 g/t Senfronth to stabilise the froth.

The ore was added to 2.5 litres of water and 2 min was allowed for conditioning to ensure total wetting of the particles before collector addition. A further 2 min was allowed for conditioning before frother addition. A final 30 s was allowed for final conditioning.

Aeration was started and the froth collected for 1 min. Froth was then collected in a separate receptacle for a further minute. Changing receptacles again, the froth was collected for a further 3 min, at which point the air flow was turned off and 35 g/t collector added and 2 min allowed for conditioning before addition of 35 g/t frother. A further 30 s was allowed for conditioning.

Flotation was then continued for 15 min. Each flotation concentrate was filtered, dried and the copper content determined by atomic absorption spectroscopy. All experiments were carried out in duplicate and the values found to be within ±2% of each other.

**Determination of the Effect of Microwave Radiation on Magnetic Separation**

Palabora Mining Company, Ltd distinguishes between high- and low-titanium content magnetite. This distinction is necessary as low-titanium magnetite is sold for use in dense media separation in coal cleaning plants. As the complete magnetic separation flow sheet at PMC, Ltd is complex, single stage magnetic separation tests have been used to assess the effect of microwave radiation on magnetite recovery.

Using a spinning riffle, 100g representative samples of the untreated and treated material were obtained for use in laboratory scale magnetic separation trials.

The magnetic separation trials were conducted using a single pass Boxmag Rapid (BHW) wet magnetic separator operating with a peak field intensity of 1200 gauss. The ferrous iron content (FeO) of each sample was determined in duplicate by titration with potassium dichromate after decomposition in a sealed tube.

**Results**

**Grindability Study**

Figure 1 shows the effects of varying power 2.45GHz microwave radiation on the Bond Work Index of ore from Palabora open pit.

Figure 1 clearly shows that microwave treatment has had a significant effect upon the work index of this ore. The most spectacular influence has been in the initial treatment period where the work index is shown to reduce from 13.06 kWh/t to 9.2 kWh/t after 10 seconds' irradiation. A similar reduction is shown for the same time period for material treated at 1.5kW. Ore treated for 10 seconds in the monomode 1.5kW microwave heater shows a decrease from 13.06kWh/t to 7.7 kWh/t. The reason for this larger decrease in work index, despite lower applied power level (than the 2.6kW samples), is the mode of application of energy. In general, monomode systems, due to the nature of the presentation of the energy to the sample are more efficient...

![Figure 1—Effect of microwave radiation upon Bond Work Index (kWh/t)](image-url)
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It can be seen from Figure 3 that microwave treatment has had a significant effect upon the froth flotation of this ore. If the recoveries after 5 minutes' total flotation time are compared, it can be seen that for all samples, except that treated for 10 seconds, recovery has fallen. Recovery for the 10 second treated sample is 69.7% after 5 minutes' flotation, compared with 68.75% for the untreated sample. The reason for this increase is possibly liberation of the copper sulphide minerals away from the gangue, and other minerals in the matrix. However, it is important to note that the microwaves have caused no detrimental effect to the flotation of the sulphide species (for low exposure times). This is shown in Figure 4. The explanation for the reduction in copper recovery for samples exposed for longer than 10 seconds is oxidation of the copper sulphide species. SIBX will not form stable products with oxidized copper sulphide species, therefore the recovery falls. An interesting observation from Figure 3 is, however, that after the final scavenge float the total recovery of copper is not affected until after 90 seconds' microwave treatment. Figure 5 shows a back scattered SEM micrograph which illustrates the development of partial melt products after 120 seconds' microwave treatment at 2.6kW. The formation of these partial melt products will obviously affect the flotation of the ore (particularly if copper sulphide species are involved as in Figure 5) The copper recovery for ore treated at 2.6kW for 4 minutes is 77.7%, compared with 86.94% for untreated material.

Figure 2—False colour SEM micrograph of 180 seconds treated ore sample (2.6kW, 2.45GHz)

Figure 3—Effect of microwave radiation upon flotation (air treated)

highly porous and therefore weaker than before treatment. Dolorite has been shown to cause particular problems in the grinding circuit at Palabora mine as it has a high value of work index (~30kWh/t) so this decomposition is very important.

Flotation Study

Figure 3 shows the effect of microwave radiation upon Palabora ore treated in air.
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Figure 6 shows the effect of microwave treatment utilising an inert nitrogen atmosphere upon the flotation of this ore. If the recoveries after 5 minutes are compared, it can be seen that after 10 seconds' and 30 seconds' treatment slight increases in recovery occur when compared with untreated material. The recovery after 10 seconds' treatment and 5 minutes' flotation being 72.7% and for 30 seconds' treatment and 5 minutes' flotation 70.8%. This increase, again, can be explained by the phenomenon of thermally assisted liberation, as illustrated in Figure 4. The untreated recovery after 5 minutes' flotation was 68.7%. After 30 seconds' microwave exposure recovery fell with increasing exposure time. The final recoveries for all samples treated in a nitrogen atmosphere are similar, indicating that the overall flotation process was not affected by the nitrogen treatment.

It is possible that the effects of thermally assisted liberation could be exploited for higher exposure times by changing to a different collector. SIBX is a very selective collector, the use of Sodium Iso Propyl Xanthate (less selective) may mean higher initial recoveries, even for samples that have undergone oxidation. However, considerations of grade would have to be made.

Magnetic Separation Tests

Figure 7 shows the effect of varying power microwave radiation upon single stage magnetic separation tests. It can be seen that microwave treatment has had a considerable effect on the recovery of FeO. For material treated at 2.6kW the most significant change occurs within the first 10 seconds of treatment. After this time a recovery of 77% is observed, compared with 72% for non-treated material. After 10 seconds the recovery of FeO falls to 74.5%, which is still higher than untreated ore. A similar figure is obtained for material treated for 60 seconds. If tests had been carried out on material exposed to 2.6kW radiation for longer, reductions in recovery below that of untreated material would have been seen. This is due to the partial melting and magnetite oxidation that is shown in Figure 6 and also Figure 8. It appears that for material exposed to an applied power level of 2.6kW any more than 10 seconds' treatment is causing mineralogical changes within the sample. Figure 7 also shows the effects of 1.5kW microwave radiation upon recovery of FeO. In general, the recovery remains fairly steady until after 90 seconds' treatment, where a recovery of 76.5% compares with a non-treated value of 72%.

The effects of 1.5kW microwave treatment upon the magnetic separation of this ore are also presented. Microwave exposure of this material was carried out in an inert N₂ gas atmosphere. Oxidation of the contained magnetite could therefore not happen. The microwave generation device used also supplied energy to the samples.
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using the more efficient monomode-type waveguide. After the first 10 seconds microwave treatment, the recovery can be seen to have increased from 72% for non-treated material to 79%. For the next 50 seconds’ exposure, the recovery stays constant (there is no sign of reduced recovery due to oxidation). After 90 seconds’ total treatment the recovery increases further from 79% after 60 seconds to 83%. Further exposure times were not investigated.

The probable reason for the increase in recovery for microwave-treated samples is similar to that for the increases in recovery after flotation. Microwave treatment induces differential heating in the ore matrix. This differential heating leads to differential expansion at grain boundaries causing the propagation of intergranular fracture. Intergranular fracture leads to the liberation of whole mineral particles and therefore possible increases in recovery. Where recovery has fallen (particularly in the samples treated at 2.6kW) partial melting or oxidation of the magnetic species has occurred, lowering the magnetic susceptibility of the ore; thus FeO recovery is lower.

Economic Analysis of Microwave Treatment

USIMPAC software supplied by BRGM, France, was developed to allow the modelling of mineral processing flowsheets. The effects of altering variables on any given flowsheets can easily be quantified. It is useful to have actual plant data to configure and test the models, prior to running iterations. More information regarding the models used for each individual piece of equipment is given in the literature (Anon, 1999). The software was used to model the Palabora Mining Company, Ltd conventional grinding flowsheet. This flowsheet consists of an open circuit rod and ball mill, followed by a close circuit ball mill.

For each mill in the circuit the following information was supplied.

- Diameter and length
- % Critical Speed
- Volumetric loading of rods/balls
- Rod/ball SG
- Work Index of Material. (kWh/t)

For cyclones the following data were required

- Cut point (µm)
- % Solids in underflow

The streams entering the primary rod mill above were described, using the size distribution from all grinding tests. The $d_{80}$ of this stream was approximately 16 mm. However, the $d_{80}$ of the rod mill feed at Palabora mine is slightly smaller at 11.2 mm. The model was run using actual plant data from Palabora mine (Henderson, 1980) (except $d_{80}$ of the feed). The model was tested by comparing predicted and true values of circulating load. The model predicted the circulating load to be 277%, assuming a $d_{80}$ input size of 16mm. The actual circulating load on plant is approximately 250% for a feed with a $d_{80}$ of 11.2 mm. From this it was assumed that the model was a reasonably accurate replication of the plant.

The effects of microwave treatment upon the ore were investigated by changing the parameter of Bond work index and calculating the circulating load. The values of Bond work index used for the tests were obtained from Figure 2 from exposure times of 10, 30 and 90 seconds. The values of work index were input into the model for each mill and the model run as for the configuration test. Figure 9 shows a plot of circulating load versus Bond work index. The effect of changing the grindability of the ore on the circulating load can clearly be seen. As Bond work index is decreased so does the circulating load. In fact if the work index is reduced as far as 2kWh/t (as is indicated possible by the experimental tests) the circulating load is totally removed. This obviously has significant implications for the energy requirements for the processing of this ore. The practical implication of reducing the Bond Work Index of the ore as low as 2kWh/t is (according to the simulation) to allow the same product size distribution at the same plant.
throughput with just a closed circuit rod mill. In practice, reducing the Bond Work Index of the ore will significantly increase the plant throughput for a set flowsheet.

Electrical energy consumed by comminution processes has been shown to account for approximately 5% of the total world energy consumption (Schwechten et al. 1990). This obviously justifies investigations into methods to reduce energy input for size reduction. This paper has demonstrated that microwave energy can have a significant effect on the grindability and downstream processing of Palabora ore.

Accurate prediction of process energy requirements for laboratory microwave treatment is difficult. Reasons for this include scale factors, (surface to volume ratio and heat loss effects), difficulties in calibration of power sensors, non-optimal applicator designs with high reflected powers and low magnetron efficiency. Based upon the results of the following tests it can be seen that to reduce the work index of the ore from 15.1kWh/t to 2kWh/t takes irradiation at 2.6kWh for 180 seconds. Therefore, it can be shown that for a 1kg sample of ore:

\[ 2.6 \times 180 / (3600 \times 0.001) = 150 \text{kWh/t} \]

For 10 seconds’ exposure this energy input is reduced to 7.2kWh/t for a reduction in Bond work index of 4.1kWh/t. It is clear from these figures and also the mineralogical investigation that to expose ore for 180 seconds is pointless as the micro-structure and mineralogy is destroyed (admittedly giving large reductions in Work Index). Ten seconds’ exposure, however, gives a reduction in required grinding energy of 4.1kWh/t for an energy input of 7.2kWh/t. The benefits of microwave treatment of ores do not extend solely to reductions in required grinding energy. As has been demonstrated in this paper, consideration must be given to increases in grade and recovery of valuable minerals, increases in plant throughput, liberation of valuable minerals at higher grind sizes, therefore reducing slimes production, and also reductions in plant wear (particularly media and liner). In carrying out a full techno-economic, however, the following points must also be considered. This test work was carried out using laboratory scale equipment. Such equipment is unlikely to have an energy efficiency of much above 40%, for the reasons stated above. Industrial scale microwave systems have the advantage that they operate at above 40%, for the reasons stated above.

Industrial scale microwave equipment is available that will produce about 70kW in continuous operation. Clearly, for a plant like PMC, Ltd, many generators would be required. The capital cost of industrial microwave equipment has been estimated at $1200 per kW for high power systems (Van Wyk, 1997) and the capital cost of such systems will undoubtedly be significant. It will be vital that energy input to the system be minimised and therefore work is currently being undertaken at the University of Birmingham concerning the application of ultra high electric field strength microwaves to minerals and ores on a continuous basis. When this data is available, a full techno-economic analysis of the application of microwave radiation to PMC, Ltd ore will be possible. Work is also underway at the University of Birmingham to optimise the application of energy to the sample. It has been concluded by other workers (Stein et al. 1994) that failed applications of microwave energy were mainly due to the poor design of the application equipment. This should be remembered when applicator design is carried out for any process which requires microwave energy.

Conclusions

This study has clearly demonstrated the effects of microwave radiation upon the processing of ore from Palabora mine and the influence of significant reductions in work index have been demonstrated upon a part of the grinding circuit. As energy is being added to the process, however, a full techno-economic analysis is required to prove the benefits of microwave treatment for ores of this type. The reductions in work index, coupled with increases in recovery of valuable mineral, in addition to other benefits such as less mill wear and higher plant throughputs, must be balanced against both the capital and operating costs of this technology.

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References


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SCHWECHTEN, D. and MILBURN, G.H. Experiences in Dry Grinding with High Compression Roller Mills for end Product Quality Below 20 Microns.

The demise of EPPIC*

With the concurrence of its member institutes, the decision was taken at a meeting on 2 March 2000 of the Central Committee of the Environmental Planning Professionals’ Interdisciplinary Committee (EPPIC) to wind up its affairs forthwith. The balance of any funds remaining would be distributed among member institutes in good financial standing. The future of the prestigious EPPIC Awards remains open.

The demise of EPPIC was brought about by diminishing financial and direct support for this umbrella body which represented the responsibilities and interests of a number of professional institutes towards the environment.

One feels ambivalent about the situation, but it is probably fair to say that EPPIC had accomplished its Mission and should now retire with dignity and pride.

EPPIC was formed in 1974 in response to a general criticism of the disregard of environmental factors by the planning professions, expressed in 1973 at a conference arranged by the South African Institution of Civil Engineers (SAICE) on Transportation and the Environment.

SAICE played a leading role in the formation of EPPIC in requesting Mr E J Hall, then President of SAICE, to convene a meeting of concerned professional institutes of those professions which commonly initiate, plan or act as the principle agent in the planning and execution of developments which could have significant impacts on the environment.

The SAIMM joined EPPIC shortly after its inception and was represented on its Central Committee by Peter Harris. He was succeeded in the mid 1980s by John Freer, who in 1988 recommended to Council the formation of a Committee for the Environment within the administrative structure of the Institute. This was done the following year with a view to integrating environmental issues into the work of all relevant committees of the Institute, such as the Technical Programme Committees and the Journal, Education and Awards Committees, while the Chairman represented the Institute on EPPIC’s Central Committee and reported to Council. The SAIMM was probably the only member institute of EPPIC to adopt this ideal model whereby environmental matters were thoroughly integrated into its management structure. Had all member institutes done likewise, support for EPPIC would have been unequivocal and the reflection of the execution of EPPIC’s mission by all members of all its member institutes that much more complete and lasting.

Be that as it may, the facts of the matter are that, in the absence of relevant legislation, EPPIC was formed to encourage the professional planning institutes, and through them their members, to take environmental factors into account proactively and voluntarily during the planning, execution, operation and closure of all their projects. Members can look back with pride regarding the progress made in this regard over the last 25 years.

Today legislation is in place to enforce good practice in environmental management in the form of the National Environmental Management Act (NEMA) (1998) which incorporates aspects of the repealed Environmental Management Act (1989) and its regulations, as well as, more specifically for the mining industry, the EMP requirements of the Minerals Act (1990).

Hopefully, EPPIC’s influence will continue to pervade the minds of the members of this institute, encouraging them to be proactive towards the early identification of those aspects of their activities that could have a significant impact on the environment, eliminating those that they can and ameliorating the rest, while seeking continual improvement in this regard.

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