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Monday November 8th

08.00 Registration desk opens

09.00 Opening Remarks
J. Wills (MEI, UK) and S.T.L. Harrison (University of Cape Town, South Africa)

09.20 *Technical Session 1*
Chairmen: A. Kaksonen (CSIRO, Australia) and P. d'Hugues (BRGM Environnement & Procédés, France)

09.20 **The bioleaching of six nickel sulphide ores with differing mineralogies in stirred-tank reactors at 30 ºC**
R.A. Cameron, K.J. Kennedy (University of Ottawa, Canada), R. Lastra et al (Natural Resources Laboratories, Canada)

A bioleaching study was conducted with six different nickel sulphide ores from different geographical locations across Canada. Mineralogical and chemical examination of the ores revealed considerable variability between the samples. The ores contained 0.31 to 0.99% nickel, primarily as pentlandite and pyrrhotite. All ores were subjected to the same crushing and grinding protocol and bioleached under the same conditions for three weeks with a mixed-culture of iron- and sulphur-oxidizing bacteria. A total of fifty-three stirred-tank experiments with finely ground (-147 µm) ore at 30 °C were conducted to assess the effect of pH (2 to 5) and the impact of the bacteria. The extraction of nickel from pentlandite and pyrrhotite was generally good (49 to 86% after three weeks) and exhibited little dependency on acidity at pH $\leq$ 3.

09.40 **Bioleaching and recovery of metals from final slag waste of copper smelting industry**
A.H. Kaksonen, L. Lavonen, M. Kuusenaho, A. Kolli, H. Närhi, J.A. Puhakka (Tampere University of Technology, Finland), E. Vestola (VTT Technical Research Centre, Finland) and O.H. Tuovinen (Ohio State University, USA)

Solid waste from copper smelting industry may be harmful if disposed of in the environment, but it may be a valuable resource if metals can be recovered. The purpose of this study was to evaluate the acid bioleaching of metals from a sample of final smelter slag. Bioleaching was tested in a continuously stirred tank reactor (20-25 °C) with 5% pulp density (particle size 75% <47 µm). Metal yields after 29 days of contact were 41% Fe, 62% Cu, 35% Zn and 44% Ni. Metals were precipitated in a separate reactor by titrating the leach solutions with sulfide-rich effluent from a fluidized-bed bioreactor to different pH values. Over 92 % Cu precipitated at pH$\geq$ 2.7 and over 99% Zn precipitated at pH$\geq$ 3.9. The precipitation of Ni and Fe required higher pH values and was less efficient.

10.00 **The generation of toxic reactive oxygen species from mechanically activated sulfide concentrates**
G.C. Jones, R.P. van Hille and S.T.L. Harrison (University of Cape Town, South Africa)

The mechano-chemical effect of milling sulfide concentrates for the purpose of mechanical activation prior to tank bioleaching is not clearly understood despite being widely practised in industry. Some of the hydrometallurgical advantages of mechanically activating concentrates via fine milling are increased leach rates, increased metal extraction efficiencies and decreased pulp retention times. There is also an increasing trend in tank bioleaching technologies being applied to reprocess sulfide tailings for the economic recovery of residual valuable metals, especially gold and cobalt. This has the advantage of being essentially free of the economic costs associated with concentration process steps. These justify increased attention being placed on the choice of fine milling equipment and the impact of the mechano-chemical treatment on tank bioleaching performance under different conditions.

The generation of reactive oxygen species (ROS) from sulfide concentrates has been studied with respect to mineral composition and surface area loading under thermophilic bioleaching conditions previously. Results showed that the concentration of toxic reactive oxygen species (ROS), including hydrogen peroxide and hydroxyl radicals, generated from different sulfide concentrate samples, was approximately proportional to the grade of iron containing sulfide minerals, such as chalcopyrite and pyrite present in all of the samples tested. In this study, two types of laboratory mills (planetary and vibratory) were used to prepare samples of differing particle size distribution. These were characterised in terms of surface area, density and XRD spectral peak line broadening. ROS generation increased with increasing time periods of mechanical activation (*i.e.* milling time). Increased ROS generation is postulated to be caused by a combination of increased surface area and bulk particle-related defects and transformations, resulting in increased reactivity on contact with acidic solution. The ROS generation profiles differed between the two mills. This could be explained by comparing the particle breakage mechanisms of the two mills. Bioleaching tests showed that samples that were briefly activated mechanically showed improved leach performance compared to unactivated head grade samples; however poor bioleaching performance followed prolonged mechanical activation where, in extreme cases, a complete

lack of inoculated cells was observed after a few days of exposure via fluorescent microscopy suggesting complete culture death.

10.20 **The efficiency of indigenous and designed consortia in bioleaching stirred tank reactors**
C.G. Bryan (University of Cape Town, South Africa) C. Joulian, P. Spolaore, S. Challan-Belval, H. El Achbouni, D. Morin, and P. d'Hugues (BRGM Environnement & Procédés, France)

Fundamental to the efficiency of bioleaching is the establishment of an active microbial population. There is some debate as to whether an indigenous microbial population is necessarily superior to one composed of microbial strains selected for specific physiological traits. To this end, the bioleaching efficiency of three microbial populations was studied: The indigenous population of a commercial bioleaching system (KCCL), a consortium of the three major organisms which comprise KCCL that had been 'un-adapted' through a period of continuous maintenance in synthetic media (KCCR) and a specifically designed consortium of bioleaching organisms (KCCD). The results presented in the paper imply that bioleaching consortia cannot be assembled 'off-the-shelf', at least not without a substantial period of adaptation. Moreover, the performance of the un-adapted consortium was similar to that of the indigenous population, and improved over time. This is despite the absence of an obligate sulfur-oxidising species, which resulted in the generation of substantially less acid.

10.40 Coffee

11.20 **Bioleaching strategies for the treatment of nickel-copper sulfide concentrates**
M. Gericke and Y. Govender (Mintek, South Africa)

Different process options for the bioleaching of nickel-copper containing sulfide concentrates were evaluated. Tests in continuously operated systems showed >98% nickel extraction at temperatures ranging between 37and 70°C, whereas for copper, occurring as chalcopyrite, extractions of >95 % could only be achieved at 70°C. Further optimisation of the process focused on determining the effects of process parameters such as temperature, grind size, residence time, redox control and feed solids concentration on the leach kinetics, metals extractions and performance of both moderate thermophile and thermophile cultures. Redox control in the first-stage reactor resulted in considerably faster copper leach rates and extractions of up to 95% could be achieved at increased feed concentrations and coarser grind sizes. High redox levels in the secondary reactors ensured >98% nickel recoveries. These operating conditions and control strategies have the potential to significantly increase the rates of nickel and copper extractions to the extent that leaching times can be considerably reduced.

11.40 **Respirometry studies of bioleaching of low grade chalcopyrite ore using six acidophilic strains**
J. Song, P.D. Franzmann, A.H. Kaksonen (CSIRO Land and Water, Australia), J. Lin and J. Lin (Shandong University, China)

Respirometry was used to study the growth and activity of six pure cultures of acidophilic bioleaching strains grown on a concentration series of low grade chalcopyrite ores under various pH and nutrient conditions. *Sulfolobus metallicus*, *Acidithiobacillus ferrooxidans*, *A. brierleyi* and *Leptospirillum ferriphilum* were able to grow on a very low grade ore (equivalent to 0.1% Cu content). However, the two sulphur-oxidizing bacteria *A. caldus* and *A. thiooxidans* grew poorly on low ore grade. Growth rates of all strains, except for perhaps *Sulfolobus metallicus* at highest ore grades, displayed growth that was limited by substrate availability on this low grade ore (0.5% Cu content in the ore). The decrease in solution pH from 3.0 to 1.0 enhanced both the cell growth and Cu dissolution. The addition of Fe^{2+} or S^0 as energy substrates facilitated growth and Cu dissolution by the six strains grown on low grade chalcopyrite to some extent.

12.00 **Non-traditional operating conditions for a copper concentrate continuous bioleaching**
P. Spolaore, C. Joulian, Y. Ménard and P. d'Hugues (BRGM, Service Environnement et Procédés, France)

Lubin copper concentrate is produced by flotation from a black shale organic rich ore. Due to ore particular characteristics, the flotation process is facing technical difficulties and concentrate quality (copper and arsenic grades) is degrading over time. As a consequence, research on alternative technologies to pyrometallurgy is necessary.

Bioleaching efficiency was already demonstrated during Bioshale FP6 European project. However, some improvements still needed to be achieved in order to meet process economic viability. In the frame of Promine FP7 European project, our study aimed at improving the profitability of the continuous bioleaching of the Lubin concentrate in stirred tank reactors. Non traditional operating conditions were tested: high solids concentration (> 20% solids) and reduced agitation and aeration rates. The follow-up of the experiment consisted in both physical parameters measurements (pH, Eh, oxygen uptake rates…) but also in the monitoring of the bacterial population using molecular biology techniques.

12.20 **Fluoride ion effects on the kinetics of ferrous iron oxidation by *sulfobacillus thermosulfidooxidans***
L.C. Sicupira, T.C. Veloso, I.C.B. Rodrigues, V.A. Oliveira and V.A. Leão (Universidade Federal de Ouro Preto, Brazil)

Bioleaching now is a proven technology largely applied to the processing of refractory gold, secondary copper and nickel sulfide ores. Bioleaching is mostly carried out with mesophile bacteria, especially those belonging to the *Acidithiobacillus* group. More recently, high temperature bioleaching has become relevant since the leaching rate can be increased, being *Sulfobacillus thermosulfidooxidans* the most studied bacterium. Conversely, fluorine-containing minerals, such as fluorite and fluorapatite when associated with metal sulfide ores are dissolved as the sulfide minerals are bioleached for metal recovery. At pH lower than pKa, fluoride ions are protonated as hydrofluoric acid (HF),

existing as such in the leaching liquor because bioleaching is normally carried out in pH 1,5-2. There is strong evidences that HF can go through the bacterial cell membrane easily inhibiting bacterial growth, and consequently, causing adverse effects on iron biooxidation. In this work, fluoride ions influence on the kinetics of ferrous iron biooxidation with *Sulfobacillus thermosulfidooxidans* (DSMZ 9293) was studied. The experiments were carried out in batch mode (2L STR) and the effect of fluoride concentration (0-10mg/L) on the iron oxidation and bacterial growth rates was assessed. In all experiments, the initial ferrous iron concentration was maintained at 2,5g/L; pH at 1,5; temperature at 50°C, air flow at 1L/min; and stirring speed at $300min^{-1}$. It was also assessed the effect of aluminum (Al^{3+}) additions aiming to reduce free fluoride concentration through the formation of stable aluminum-fluoride complexes, which cannot cross the bacterial cell membrane. The results show that 10mg/L F^- completely inhibits bacterial growth. Nevertheless, fluoride toxicity to *S. thermosulfidooxidans* can be minimized by controlling the ratio aluminum to fluoride in the system. At 2:1 aluminum to fluoride ratio, bacterial growth is similar to that observed in the absence of anion.

12.40 Lunch

14.00 *Technical Session 2*
Chairman: S. Ndlovu (Wits University, South Africa)

14.00 **Microbial growth rates of mesophilic acidophiles on low grade whole ore containing chalcopyrite**
S. Minnaar, O.V. Tupikina, R. van Hille, N. van Wyk, S.T.L. Harrison (University of Cape Town, South Africa), S.J. van Rensburg (Mintek, South Africa), D. Rautenbach and D. Dew (BHP Billiton, South Africa)

The research investigated the growth of a mesophilic population of acidophilic chemolithotrophs, inoculated from low inoculum, on whole chalcopyrite ore. A series of glass reactors were used for heap imitation.

In the first phase, inoculum size was investigated using five columns with inoculum concentrations ranging from 10^2 to 10^6 cells/gram. A clear relationship between inoculation size and lag time was evident, with the column containing the highest amount of inoculum first reaching high Eh values.

In the second phase, colonization on the whole ore was studied over a first 50 days period using the lowest inoculum concentration. Ten columns were inoculated with 10^2 cells/gram and a column was stopped for analysis after every five days. Cells were detached from ore and DNA was extracted. Quantitative and qualitative changes of the microbial population were investigated using qPCR and specific primes designed for the microorganisms present in the inoculum. The importance of *Acidithiobacillus ferrooxidans*, *Acidithiobacillus. thiooxidans* and *Leptospirillum ferriphilum* were shown during start-up heap colonization.

14.20 **Inhibition of the bioleaching organism acidithiobacillus thiooxidans by SDS addition**
H.-M. Siebert, R. Marmulla and K.-P. Stahmann (University of Applied Science Lausitz, Germany)

The inhibition of bioleaching by sodiumdodecylsulfate known for large scale percolators in Romania was shown for pure cultures of sulfur-oxidizing *Acidithiobacillus thiooxidans* DSM 622 and german sand samples.

A decrease of 25 to 75% in planctonic cell number counted for 10^{10} *At. thiooxidans* cells with a Thoma-chamber 30 minutes after exposure to SDS concentrations from 0.5 to 10 g/L suggested a cell lysis. Additionally a release of nucleic acids was found.

To apply these results in a more natural habitat columns filled with aquifer material from an East German lignite mining area containing 1% pyrite were treated.

Columns were washed once with 2g/L SDS and afterwards with rainwater.

Most-Probable-Number determinations of flow-through or sand revealed no growth of iron- and sulfur-oxidizing microorganisms within 25 weeks while up to 10^6 cells were determined in the control. Elution of sulphate dropped to 25%.

14.40 **Laboratory simulation and optimisation of stope leaching of low-grade uranium ore**
K.M. Penman**,** D.J. Sapsford (Cardiff University, UK), R.J. Bowell and M. Dey (SRK Consulting, UK)

This paper presents data from a laboratory simulation of an innovative underground leaching process. The experimental procedure simulates existing underground in-situ reactors where uranium is liberated from the host rock through periodical flushing with recycled leachate. This study examines the influence of varying cycle protocol on uranium leaching.

Protocol variants examined include variation of flushing frequency, flush volume, leachate recycle, nutrient solution (NPK) addition to reactors and Fe(III) sulfate addition to reactors. The data show that the time between flushes has a significant effect on the amount of uranium extracted and that addition of Fe(III) sulfate (0.5g/L) reduced the lag time before extraction. The presented data highlight the sizeable improvements in uranium recovery that might be achievable by varying the operating protocol for the operational underground reactors.

15.00 **Large particle effects in chemical/biochemical heap leach processes - A review**
Y. Ghorbani, J. Petersen, M. Becker, A. Mainza and J.-P. Franzidis (University of Cape Town, South Africa)

Heap leaching is gaining in popularity as a low cost technology for mineral extraction from low-grade ores. Unique to heap leaching is the relatively coarse particle size distribution, typically 12-25 mm top size for crushed and agglomerated ores and larger for run-of-mine dump leaching operations. Leaching from such large particles is poorly understood and commonly assumed to follow shrinking core type behavior, although this is a gross simplification in most cases.

At the particle scale, leaching is governed by the way in which mineral grains are distributed within a single particle and how well they are accessible through pores and cracks to leaching reagents flowing through the heap bed. This review investigates the current state of knowledge with respect to the understanding of leach mechanisms and mineral distributions prevailing in large particles in heaps and the tools to characterize these.

The economics of heap leaching are strongly governed by the trade-off between slow rate of leaching from large particles and the cost of crushing finer. A sound understanding of the underlying mechanisms will greatly inform future technology choices in the area of heap leaching.

15.20 **Performance evaluation of the Skorpion Zinc pinned bed clarifiers**
S. Dowling, B. Plaatjies (Skorpion Zinc, Namibia), H. Fuls (Anglo American Asset Optimisation, South Africa) and M. Langton (Roymec Technologies, South Africa)

In June 2009, Skorpion Zinc commenced with hot commissioning of three Pinned Bed Clarifiers (PBC). The units are designed to clarify solution to 10 mg/l total suspended solids (TSS) from a pregnant leach solution containing 50 to 100 mg/l TSS at an upflow velocity of 7.1 m/h. The minimum target period between backwashes is 24 h.

This paper discusses commissioning and operational challenges of the full-scale units (*e.g.* sludge removal point, media particle size and flocculant dosing) with reference to parameters determined during piloting. The performance of the full-scale PBCs in terms of overflow clarity, period between backwashes, runtime, and unit availability is presented.

Achieving consistent 24-hour period between backwashes remains a challenge. Backwashes occur more frequency when solids accumulate on the sides of the PBC cone instead of reporting to the sludge recycle stream. Operational solutions include reduction of flocculant concentration, improved flow control to individual PBCs and the installation of a cone rake.

15.40 **Gas phase metal extraction case study: the extraction of iron from iron(III) oxide**
L.D. van Dyk, E. Mariba (University of the Witwatersrand, South Africa), Y. Cheng (University of Nottingham, UK) and J.H. Potgieter (Manchester Metropolitan University, UK)

Extraction processes that utilise organic ligands in the gas phase differ from conventional energy intensive pyrometallurgical processes as well as harsh chemical extraction techniques, in the sense that it is less energy intensive and the possibility exists to recover and reuse the ligand. Even though the technology was first proposed in the 1980s, little is known about the reaction kinetics and practical applications of such processes. As part of an ongoing investigation into the application of gas phase extraction, the extraction of iron from iron(III) oxide was studied in a fluidised bed. The reaction conditions were varied to study the influence of reaction temperature, ligand concentration and metal oxide concentration on the extraction kinetics. At low iron(III) oxide concentrations more that 80% of iron was successfully extracted after 4hrs using the ligand, acetylacetone. It was also found that all three reaction variables have an influence on the extraction kinetics.

16.00 Coffee

Tuesday November 9th

09.00 *Technical Session 3*
Chairmen: L.D. van Dyk (Wits University, South Africa) and C. Bryan (University of Cape Town, South Africa)

09.00 **High pressure acid leaching of Turkish laterites**
Y.A. Topkaya and Ş. Kaya (Middle East Technical University, Turkey)

In this study; the fundamental HPAL (High Pressure Acid Leaching) process parameters like leaching duration, temperature, sulphuric acid/ore ratio, feed size, heat treating of the ore prior to the leaching process, effect of additions such as HCl, NaCl, Na_2SO_4, and $FeSO_4$ on nickel extraction from the Western-Anatolian, Manisa/Gördes limonitic and nontronitic nickel laterite ores were studied and the optimum values have been determined as process parameters for these lateritic type nickel reserves.

09.20 **Profiling of bioleaching organisms in BIOX® reactors from different locations**
R.P. Van Hille, S.T.L. Harrison and N. Van Wyk (University of Cape Town, South Africa)

The BIOX® process was developed in the late 1970's by Gencor for the processing of refractory gold ores. The technology was commercialised in the mid 80's and there are currently over 10 commercial scale plants operating worldwide. The process relies on the action of acidophilic iron and sulphur oxidising microorganisms. During the development phase the population was thought to consist of *Acidithiobacillus ferrooxidans*, *At. thiooxidans* and *Leptospirillum ferrooxidans*. The increased accessibility of PCR based molecular biology techniques led to renewed research into the population structure of BIOX® reactors and it was determined, by Coram and Rawlings, that a newly described species *Leptospirillum ferriphilum* and *Acidithiobacillus caldus* dominated the commercial scale reactors. This was attributed in part to their higher temperature optima, which provided a competitive advantage as reactor temperatures were pushed higher to enhance leach rates. There has been little microbial ecology work on the BIOX® process in the past eight years. The current work describes the quantitative characterisation of the microbial population from a number of BIOX® reactors located in South Africa and Ghana. The works makes use of a relatively new technique, quantitative real-time PCR, which allows concentration of particular species in a reactor to be determined based on extracted DNA. While the technique has limitations which make absolute quantification to cells/ml difficult, relative population structures can be accurately determined. The data show that the Fairview sample was most characteristic of a "typical" BIOX® population, being dominated by *L. ferriphilum*. The samples obtained from the Ghanaian reactors showed population structures very different from what was expected. All the reactors tested showed significant numbers of archae from the genus *Ferroplasma*. These dominated most of the Ghanaian reactors and were found in substantial numbers in the South African samples. *Ferroplasma* species have not previously been described as important members of the BIOX® community. The possibility exists that they have been present from the start, but were not quantified because research focussed on the bacterial component. In addition to *Ferroplasma*, members of the genus *Sulfobacillus* were found to dominate several of the Ghanian reactors, particularly in the case where temperature control had been compromised and the temperature increased above 45°C. Subsequent temperature correction resulted in a decrease in the concentration of *Sulfobacilli*. The contribution of the *Ferroplasma* and *Sulfobacillus* species to the overall performance of the BIOX® process, particularly at elevated temperatures is not known and offers and interesting research opportunity.

09.40 **Interaction of microorganisms in a hematite-quartz flotation system**
N.A. Abdel-Khalek et al (CMRDI, Egypt), H. Rao (Luleå Technical University, Sweden) and A.-H. Kandel (Helwan University, Egypt)

The increasing world demand for mineral raw materials has led to the exploitation of low-grade ores. This fact associated with more rigorous specification of concentrates, hard environmental legislation and a necessity to achieve lower operating costs has led to numerous investigations aimed at finding better processing techniques and more effective notation reagents.

Recent literature has showed microorganisms can be used as flotation reagents. In the present study, a group of microorganisms has been investigated as a flotation reagent for the hematite - quartz system. The studies were based on zeta potential and adsorption measurements and micro-flotation experiments in absence and presence of microorganisms. Microbe-mineral interactions resulted in significant surface-chemical changes on mineral surfaces. The changes in zeta potential, adsorption, adhesion and flotation behavior of hematite and quartz particles after microbial interaction are discussed.

10.00 **Extracellular polymeric substances (EPS) from bioleaching systems and its application in bioflotation**
Y. Govender and M. Gericke (Mintek, South Africa)

EPS producing heterotrophic and chemolithotrophic bacteria have been successfully applied in flotation processes for the last two decades. These studies have been mostly confined to laboratory microflotation tests with limited information available on its application in a larger flotation circuit. In this study the effect of EPS extracted from bioleaching consortia on the floatability of chalcopyrite was determined and key process parameters (e.g. EPS concentration, flotation time, collector concentration) was optimized. Analyses of the various extracted EPS, indicated that the EPS consisting mainly of carbohydrates, proteins and uronic acids demonstrated the best chalcopyrite recovery of 77 % during the separation of pure chalcopyrite from pure pyrite. The chalcopyrite recovery could possibly be

increased by an increasing and optimizing the EPS concentration. The optimized method was then tested on a macro flotation circuit. The results obtained suggest that chalcopyrite flotation rate significantly increased in the presence of certain extracted EPS.

10.20 **Control of bacterial metal sulfide leaching processes**

B.M. Florian, N. Noël, C. Thyssen, I. Felschau and W. Sand (University of Duisburg-Essen, Germany)

Bioleaching is a process whereby bacteria dissolve metal sulfides by biooxidation.

Leaching bacteria attach to the mineral and form biofilms on the surfaces, which is relevant for the whole process. Consequently, the attachment of microorganisms as the first step in biofilm formation is the critical one. To develop methods to enhance or reduce bioleaching, our investigations are focused on the initial processes of attachment and biofilm formation.

The relevance of strain composition with respect to initial attachment processes and biofilm formation is still unknown.

Therefore, we quantified and visualized initial colonization and biofilm formation on pyrite of the genera *Acidithiobacillus, Ferrimicrobium* and *Leptospirillum* as well as of a novel γ-proteobacterium using DAPI-, Lectin or FISH- staining in combination with atomic force microscopy. Microcalorimetric measurements were used to determine metabolic activity of cells. To inhibit bacterial leaching processes, several tensides were tested, which have varying efficiency in inhibition of leaching bacteria.

We were able to show that interactions of different bacterial species resulted in increased production of extracellular polymeric substances, increased attachment and leaching rates. Another finding is that large areas of minerals remain uncolonized, whereas at some places bacteria attach in clusters.

Based on these findings we may be able to develop methods to influence attachment of bacteria and thereby to improve industrial leaching processes. Furthermore, the application of tensides can be applied as an environmental friendly countermeasure to AMD.

10.40 Coffee

11.20 **The effect of temperature on the attachment of *metallosphaera hakonensis* to a copper sulphide concentrate with application to heap bioleaching**

L. Bromfield, C.-J. Africa, S.T.L. Harrison and R.P. van Hille (University of Cape Town, South Africa)

Efficient heap bioleaching of chalcopyrite requires operating temperatures in excess of 60°C, with the heat generated primarily by the oxidation of reduced sulphur species. Successful colonisation of heaps with thermophilic archae is therefore a prerequisite. Previous studies have shown that the attachment of microorganisms to the mineral ore results in an increased rate and extent of bioleaching.

In this study the effect of temperature and culture history on the attachment of the extreme thermophilic archae, *Metallospaera hakonensis* to a copper sulphide mineral concentrate is investigated using two approaches: shake flask experiments and column experiments. The shake flask experiments were conducted to provide continuity with previous studies. The column experiments were performed using concentrate coated glass beads and provided a better representation of the hydraulic conditions found within a bioleaching heap. The analysis of cell surface properties of both the thermophile and the mineral surface has been conducted to provide an explanation for the trends observed. Attachment at 25°C, 45°C and 65°C was investigated in both sets of experiments. The results show a clear relationship between increasing temperature and attachment efficiency, which is independent of the culture history. An increase in temperature from 25°C to 45°C resulted in an improvement in attachment efficiency of between 50% and 100%, depending on the culture history, while a further increase to 65°C improved attachment by an additional 20%-50%. Cells previously maintained on elemental sulphur showed, on average, a 1.3 times greater affinity for the mineral concentrate than cells maintained on ferrous iron or the concentrate itself. In contrast to previous studies, conducted with mesophilic organisms, *Metallosphaera* did not show significantly improved affinity for sulphide mineral concentrates over low-grade ore. The data suggest that retention of thermophiles within the heap could be enhanced if they were introduced once the mesophilic pioneer species had elevated to temperature in the heap to above 40°C.

11.40 **Bioleaching of gold and copper from waste mobile phone PCBs by using a cyanogenic bacterium**

T.D. Chi (University of Science and Technology, Korea), J.-C. Lee, J. Jeong (KIGAM, Korea), B.D. Pandey (National Metallurgical Laboratory, India) and K. Yoo (Korea Maritime Museum, Korea)

This paper highlights the application of *Chromobacterium violaceum (C. violaceum),* a cyanide generating bacterium to leach out gold and copper from the waste mobile PCB sample containing around 34.5% of copper and 0.0025% of gold in YP medium (yeast extract- 5g/L; polypeptone- 10g/L; glycine- 5g/L and $MgSO_4.7H_2O$ -1g/L). The bioleaching experiments were mostly carried out at 30^oC temperature and 15g/L pulp density while varying initial pH in the range 8 – 11 and shaking in an incubator at 150 rpm. Under the above condition the amount of gold and copper solubilized in 8 days time at pH 9.0 was found to be 0.296 ppm and 415 ppm, respectively. The bioleaching of metals with *C.violaceum* was also investigated in presence of hydrogen peroxide as a source of oxygen in the system. The bioleaching of gold and copper from the waste mobile PCBs with *C.violaceum* can thus be utilized to recycle such a waste material in environment friendly manner.

12.00 **Bioleaching of printed circuit board by *acidithiobacillus ferrooxidans***
L.Harue Yamane and J.A.S. Tenório (Polytechnic School of São Paulo University, Brazil)

The present work investigated the bioleaching process to solubilize metals from printed circuit board (PCB) using *Acidithiobacillus ferrooxidans*. PCBs were collected in obsolete computers and mechanically processed through size reduction followed by magnetic separation. The bacteria *Acidithiobacillus ferrooxidans* were grown and adapted in presence of PCB. A shake flask study was realized on the PCB samples using a rotary shaker under the following fixed conditions (160 rpm, 30°C for 15 d). The influence of pH of the medium and íon ferric produced were investigated. The bioleaching process efficiency was evaluated by analysis of the concentration of zinc, copper and tin in the medium using inductively coupled plasma and compared with the initial sample concentration. The results showed that *Acidithiobacillus ferrooxidans* can leach metals from PCB.

12.20 **Getting more out of end-of-life vehicles – a bio hydrometallurgical approach**
G. Lewis, S. Gaydardzhiev, D. Bastin (University of Liege, Belgium) and P.-F. Bareel (Comet Traitement SA, Belgium)

Bioleaching experiments aimed at recovery of valuable metals (Cu, Zn, Pb) from the finest particle size fraction (below 500µm) found in the ELV shredder residues have been carried out. The preliminary results from this study program will be presented and discussed. The bacterially assisted leaching has been based on a consortium of copper-adapted mesophilic strains. Various operating conditions such as temperature (25 to 50°C), pulp solid density (5 to 20%) and initial iron concentration (3 to 15 g/l) have been tested upon the degree of metal immobilisation. Temperature has proved to be the most influential parameter regarding copper dissolution kinetics, while pulp solid density and iron concentration have been found to have a subordinate importance. Leaching durations have been found acceptable for the majority of the studied conditions with high copper and zinc recoveries being observed in the PLS. Bacterial presence has been beneficial in terms of catalysing the copper leaching reaction.

12.40 Lunch

14.00 *Technical Session 4*
Chairman: S.T.L. Harrison (University of Cape Town, South Africa)

14.00 **Commercialisation of the ASTER Process**
N. Makhotla, J.W. Olivier and C. van Buuren (Gold Fields Limited, South Africa)

Environmental legislation associated with the land disposal of cyanidation tailings and water discharge is becoming increasingly stringent world-wide, thus enforcing the treatment or recycling of contaminated water streams.

Micro organisms used in the bioleaching of sulphide minerals in particular, have a low tolerance to thiocyanate and cyanide species making the recycle of contaminated process water to the BIOX® plant impossible.

Laboratory and pilot scale testing of the ASTER process on 0.08, 6 and 25m^3 scale reactors at Fairview and Segala Gold plants yielded > 98% SCN^- removal. Based on the success and process robustness demonstrated during the various pilot runs, Barberton Mines decided during 2009 to go ahead with a full scale ASTER plant to treat contaminated water at the Consort Plant.

As part of commercialisation of the ASTER technology, a detailed Technology Mind Map was developed to ensure a comprehensive product package that develops a fundamental understanding on the process, a competent and flexible process design and also pathways for continual improvement of the technology. To facilitate the fundamental process aspects, a development program between Gold Fields and the University of Cape Town (UCT) was initiated which draws on advanced microbiological analyses and sequencing techniques. The first phase focuses on optimising the process conditions and effects of heavy metals and cyanide, and a second more fundamental phase involves modelling and characterisation of the microbial consortium.

The Consort ASTER demonstration plant has a full capacity of 320 m^3/d tailings solution and a retention time of 12.5 hours. The plant is designed for SCN^- and CN^- concentrations of 300 ppm and 40 ppm respectively. An average minimum feed temperature of 12.5 ^oC and the reactor operating temperature of 24^oC was designed for. This plant is currently under construction and commissioning is scheduled for August 2010.

The success of the Consort demonstration plant and the outcome from the UCT test program will render an ASTER Generation 1 process commercially ready.

14.20 **Sequential precipitation of Cu and Fe using a three-stage sulfidogenic fluidized-bed reactor system**
D. Ucar, E. Sahinkaya (Harran University, Turkey) and A.H. Kaksonen (CSIRO Land and Water, Australia)

The exposure of sulfides, such as pyrite (FeS_2) to water and air leads to the formation of acidic metal and sulfate containing waters, often called as acid mine drainage (AMD). Under anaerobic conditions and in the presence of a suitable electron and carbon source, sulfate-reducing bacteria (SRB) can reduce sulfate to hydrogen sulfide which can precipitate metals as low-solubility sulfides. In the present study, a three-stage fluidized-bed reactor (FBR) system was operated at 35^oC with ethanol as electron and carbon source for SRB to sequentially precipitate Cu and Fe from AMD. The system consisted of two pre-settling tanks before a sulfidogenic FBR for the sequential precipitation of Cu and Fe with biogenic H_2S gas and HS^- containing effluent, respectively. Cu and Fe precipitation efficiencies were over 99%

and sulfate and COD removals 60-90%. Biologically produced alkalinity increased the initial pH of the AMD from 3.0 to neutral values.

14.40 **Bioprocessing of coal tailings for the production of the coagulant ferric sulfate**
A.V. Colling, J.C.S.S. Menezes and I.A.H. Schneider (Universidade Federal do Rio Grande do Sul, Brazil)

The aim of this study was to evaluate the relationship between the quantity of bacteria and the rate of pyrite oxidation with the consequent production of ferric sulfate for potential use as a coagulant for water and wastewater treatment. Leaching experiments were carried out at laboratory scale with a coal tailing from Santa Catarina mining site, rich in pyrite, considering the following situations: (a) sterile conditions, (b) non sterile conditions, (c) inoculation with acidofilic bacteria, (d) inoculation with acidofilic bacteria and addition of nutrients. The source of bacteria was an acid mine drainage collected from the mining site. Water samples were collected weekly for analysis of total iron, sulfate, pH, Eh, and the most probable number (MPN) of bacteria *Acidithiobacillus ferrooxidans*. The quantity of bacteria, the pyrite oxidation rate and the production of sulfate were higher in the column inoculated with bacteria and provided the optimal conditions of nutrients. It was possible to produce an aqueous solution rich in ferric sulfate able to be used as a raw material for the production of a commercial coagulant.

15.00 **Reduction of uranium(VI) by a consortium from Limpopo grown in three different carbon sources**
S. Chabalala and E.M.N. Chirwa (University of Pretoria, South Africa)

A batch study was performed to investigate the effect of different carbon sources on biological uranium-(VI) reduction. Two homogeneous carbon sources ethanol and acetate and a heterogeneous (natural) carbon source (sawdust) were used and their impact on the U(VI) reduction rate evaluated. These carbon sources acted as carbon sources and electron donors while generating metabolites such as acetate from ethanol that were further degraded to simpler compounds by the bacteria. All cultures showed rapid reduction during the first 3-6 hours of incubation. U(VI) reduction rate determined for the highest concentration, 400 mg/L at the 50 % of added point was as high as 286 mg/L/h. Acetate derived from the sodium acetate salt yielded the best results at high initial U(VI) concentration in batches (200 and 400 mg/L). Culturing under carbon sources leached from sawdust yielded the best results only at concentrations lower than 100 mg/L (35, 75, and 100 mg/L batches). Detailed comparative performance analysis is conducted using the maximum uranium-(VI) reduction rate coefficient and uranium (VI) reduction capacity determined for the different growth conditions. The facultative anaerobic isolates of bacteria used in this experiment were obtained from a closed uranium mine in Limpopo, South Africa.

15.20 **Biosorption of yttrium, lanthanum, cerium, and neodymium from apatite leaching aqueous solution using platanus orientalis leaf powder**
E. Jorjani and S.H. Amirshahi (Islamic Azad University, Iran)

In this work, platanus orientalis leaf powder was used to extract yttrium, lanthanum, cerium and neodymium, from phosphoric acid produced by nitric acid leaching of apatite concentrate. The effects of pH, contact time, temperature, and quantity of biosorbent in sorption, and hydrochloric acid concentration in desorption stages were investigated. The results showed that leaf powder can uptake 23.2, 6, 6.89 and 3.21 mg/g cerium, lanthanum, neodymium and yttrium from aqueous solution; the extractions of 97% cerium, 82% lanthanum, 87% neodymium and 51% yttrium were achieved. Hydrochloric acid can desorbs about 99% of lanthanum and yttrium, 98% of neodymium and 97% of cerium from P. orientalis. According to the thermodynamic studies, the values of ΔH^e =0.54, 4.76, 0.22 and 0.23 KJ/mol and ΔG^e = -9.12, -9.48, -9.44 and -7.64 KJ/mol (at 30 ^{O}C) for La, Ce, Nd and Y, respectively suggest that the biosorption of La, Ce, Nd and Y on P. orientalis leaf powder is an endothermic and spontaneous process. The results indicate that P. orientalis is a suitable biosorbent on extraction of rare earth elements from phosphoric acid aqueous solution.

15.40 **Molecular characterisation of the microbial community of a full-scale bioreactor treating Bayer liquor organic wastes**
N.J. McSweeney, D.C. Sutton (University of Western Australia, Australia), A.H. Kaksonen, P.D. Franzmann (CSIRO Land and Water, Australia), A.L. Tilbury, H.J. Nyeboer and A.J. McKinnon (Alcoa World Alumina, Australia)

Sodium oxalate is an organic impurity produced by the Bayer refining of bauxite as a result of the degradation of humic materials associated with the ore. Physico-chemical oxalate destruction techniques such as combustion are often expensive and often pose greater environmental risks than the storage of solid oxalate waste. Bioreactors have provided an economical and environmentally friendly way to degrade oxalate, but the microbial communities responsible for the degradation have remained largely uncharacterised. In the present work, the microbial community of a full-scale bioreactor showing complete degradation of sodium oxalate was characterised using 16S rRNA gene clone libraries and phylogenetic analysis of the near full-length 16S rRNA clone sequences. The community was largely dominated by species belonging to the alpha-, beta- and gamma-*Proteobacteria* groups. Novel oxalate-degrading bacteria belonging to the genus *Halomonas* and the group beta-*Proteobacteria* have been isolated and are currently being characterised.

16.00 Closing Remarks
S.T.L. Harrison (University of Cape Town, South Africa) and A.J. Wills (MEI, UK)

16.10 Coffee and Wine

Posters

Some aspects of the effect of pH and acid stress in heap bioleaching
O.V. Tupikina, I.E. Ngoma, S. Minnaar and S.T.L. Harrison (University of Cape Town, South Africa)

The chemical and physical conditions in sulphide heaps provide a complex microbiological environment, with differences in redox, acidity, temperature, oxygen and solution chemistry conditions being experienced both temporally and spatially. One of the most important parameters for successful colonization and active microbial metabolism is suitable pH conditions in the heap. Typically heaps reach tens of meters high and the pH of irrigation solution travelling through heap changes significantly.

In this study, we investigated the effect of pH and acid stress for moderately thermophilic and thermophilic mixed cultures, operating at 50 to 70^{o}C in the heap bioleaching environment. Results collected from the low grade whole ore packed lab-scale column reactors irrigated with different pH irrigation solutions during a temperature shift from moderate thermopile conditions to thermopile conditions are discussed. The trends observed are further investigated in terms of microbial tolerance to acid, determined in suspended culture environments, and precipitate formations.

Adaptation of *acidithiobacillus ferrooxidans* to printed circuit board from scrap computer
L.Harue Yamane and J.A.S. Tenório (Polytechnic School of São Paulo University, Brazil)

In this study the bioleaching of printed circuit boards (PCB) from scrap computers by adapted and unadapted *Acidithiobacillus ferrooxidans* to solubilize metals was compared. The adaptation of *A. ferrooxidans* was realized by serial subculturing of the bacteria in T&K medium containing gradual increased of PCB concentration. The leaching experiments were carried out in 200ml cultures in 250 ml shake flasks containing the PCB (1.5% w/v) in T&K medium. The cultures were incubated at 160 rpm and 30 ± 2 °C. The results showed significant difference in bioleaching rate of Zn^{2+} and Cu^{2+} between unadapted and adapted bacteria. The adaptation of *A. ferrooxidans* cells to 15g/L PCB enhanced the metals solubilize from PCB.

Influence of temperature and microorganisms upon copper dissolution during waste electric cables recycling
F. Lambert, G. Lewis, S. Gaydardzhiev, D. Bastin (University of Liege, Belgium) and P.-F. Bareel (Comet Traitement SA, Belgium)

The purpose of this study has been to evaluate the technical feasibility of hydro and biohydrometallurgy for recycling of shredded electric waste cables where physical separation processes have limited success due to interconnections between copper wires and plastics.

Both chemical and bacterially assisted leaching has been carried out for recovery of copper from the plastic isolation matrix. Preliminary results are presented and discussed with regards to the influence of microorganisms used (Thiobacillus ferrooxidans and thiooxidans and Leptospirillum ferrooxidans) and temperature range (20°C to 70°C) on copper leaching rate, level of impurities dissolution and acid consumption.
Copper dissolution kinetics has been largely influenced by the temperature, reflecting on the degree of iron precipitation as well. The presence of bacterial inhibiting components from the plastics has been noted and their impact outlined.

Hydrometallurgical reclamation of Cu, Ag and Sn from waste Pb-free solder using nitric acid
J.-c Lee, E.-y, Kim, S.-k. Kim, J. Jeong (Korea Institute of Geoscience & Mineral Resources, Korea) and K. Yoo (Korea Maritime University, Korea)

The development of a hydrometallurgical process based on nitric acid leaching of the waste Pb-free solder is reported to recover copper, silver and tin. The nitric acid dissolved copper and silver from the waste material while converting tin to stannic acid (H_2SnO_3) which is very sparingly soluble in this acid. The parameters such as nitric acid concentration, leaching temperature and time, and pulp density were investigated to optimize the conditions for complete extraction of copper and silver from the waste solder, with simultaneous precipitation of high purity stannic acid. The progress of leaching reaction was monitored by XRD phase identification of the residue generated during the process. Almost complete recovery of silver was achieved from the leach liquor by cementation using copper powder as a reductant and copper was electro-won from the solution as cathode. The stannic acid of 99.9 % purity obtained from the leaching was characterized in terms of particle size and shape for its possible utilization as advanced materials.

Can active bioleaching accelerate sulphide removal from dump rock to mitigate ongoing risk of AMD formation?
A.K.B. Opitz, C.G. Bryan and S.T.L. Harrison (University of Cape Town, South Africa

Acid mine drainage (AMD) is the one of the biggest environmental challenges currently associated with the mining of sulphidic ores and coal. Formed naturally through the oxidation of exposed sulphide bearing waste rock, AMD causes severe damage both to plant and animal life over an extended geographical area and prolonged time frame. Current AMD management of waste rock and tailings focuses on preventing the formation of AMD by limiting the exposure of the waste rock to oxygen and water or the treatment of AMD formed. However, the benefit of removal of the risk of AMD formation rather than short-term mitigation is well recognised. This research focuses on the removal of the AMD

generation potential prior to the disposal of the waste rock and tailings, accomplished through the removal of the sulphidic components from the waste material to be disposed. For tailings, this removal, although potentially costly, can be achieved by separating the sulphide-bearing minerals from the more un-reactive components, providing a bulk tailings of very low sulphide for disposal without risk and a small volume high sulphide content stream for further handling (Hesketh et al. 2010, Minerals Engineering, 23, 225). Owing to limited liberation and large volumes, the potential for removal or reduction of sulphidic materials from waste and dump rock through accelerated weathering of the material is considered.

The necessary reactions to leach out the sulphide fraction can be carried out through a combination of chemical and biological reactions. The addition of iron and sulphur oxidizing micro-organisms to dump and waste rock sites has potential to promote the solubilisation of the sulphide fraction over a shortened time-frame to leave a potentially chemically inert waste rock. To achieve this, it is necessary to ensure the rapid colonisation and microbial activity in the dump, investigate the associated gangue leaching and to assess the potential to access the non-liberated sulphide fractions.

Using standard laboratory columns, the effect of the leach liquor components and the availability of liberated sulphide on the time to establish the bioleach was investigated. The results show some reduction of AMD generating potential. Particularly the tests highlight the importance of the relative time scales of acid generation and acid neutralising capacity.

Biohydrometallurgical production of hepta-hydrated iron sulfate crystals from the pyrite present in coal tailings
E.M. Vigânico, A.V. Colling and I.A.H. Schneider (Universidade Federal do Rio Grande do Sul, Brazil)

The coal mining generates large volumes of tailings that may be responsible for serious environmental damages. The oxidation of pyrite (FeS_2), in the presence of air and water, promotes the formation of the acid mine drainage (AMD), an aqueous and highly acid solution rich in sulfate and iron (in the forms Fe^{3+} and Fe^{2+}), along with other associated metals. In this study, the objective was the development of a biohydrometallurgical/UV radiation route for the production ferrous sulfate. The experimental work consisted initially in the collection of coal waste samples rich in pyrite and its characterization. I was performed, at laboratory scale, the oxidation of pyrite in aqueous medium in packed bed leaching columns in an oxidizing environment and the presence of acidophilic bacteria (*Acidithiobacillus ferrooxidans*). The recirculation of the liquor allowed obtaining an iron rich extract. The conversion of Fe^{3+} to Fe^{2+} was performed using ultraviolet irradiation (UV). Finally, the solution was evaporated allowing the formation of iron sulfate crystals. The results demonstrated that it is possible to produce high purity hepta-hydrated iron sulfate crystals having coal tailings as a raw material.

Finite difference simulation of biological Cr(VI) removal in aquifer microcosm reactors
P.J. Mtimunye, Z.M. Mboweni, D. Manyisi and E.M.N. Chirwa (University of Pretoria, South Africa)

Cr(VI) pollution of the environment results from extensive use of chromate and dichromate in industries. Industries such as metal fishing, petroleum refining, iron and steel industry, leather tanning and etc, discharge large amounts of Cr(VI) waste in the environment. Exposure to this highly toxic Cr(VI) induces acute human health risks, leading to neurotoxicity, dermatotoxicity, genotoxicity or carcinogenicity. Cr(VI) is also known to be toxic to many plants, animals and microorganisms. The purpose of this study was to develop an *in situ* bioremediation process to prevent the spread of Cr(VI) in groundwater aquifers. Microcosm columns extracted from contaminated sites were inoculated with a Cr(VI) reducing culture isolated from dried sludge from a treatment plant receiving high periodic loadings of Cr(VI) in effluent from ferrochrome processing facilities. Cr(VI) concentration was measured in the influent, in five equally spaced intermediate ports within the column and in the effluent, to facilitate finite difference modelling of the Cr(VI) concentration profile within the column. Three feed concentrations: 20, 30, and 40 mg/L, were evaluated. The systems comparisons included effects of introducing an organic electron donor (OED) and comparisons with the performance of sterile controls for each concentration. The initial results indicate that the introduction of OED resulted in increased biological Cr(VI) reduction in the columns. It was observed that the microcosm reactor with OED outperformed the reactor with no OED. Near complete Cr(VI) removal was achieved in the carbon source reactor inoculated with bacteria from sludge (after 4 days operation at 20 mg/L Cr(VI)), whereas only 69.5 % of Cr(VI) removal was achieved at 20 mg/L in sludge culture inoculated column without OED after 4 days. Up to 43.5 % of Cr(VI) was reduced under an influent concentration of 40 mg/L in a carbon source reactor after 6 days operation, whereas only 50% of Cr(VI) was reduced at 30 mg/L in a reactor without carbon source. The results are used for the optimisation of kinetic and hydrodynamic parameters (in progress) that will be used in the scale up of the system to the pilot system to be implemented at site.

Biosorption of heavy metals by algae communities in water streams impacted by the acid mine drainage in the coal mining region of Santa Catarina - Brazil
A.P.P. Freitas, I.A.H. Schneider and A. Schwartzbold (Universidade Federal do Rio Grande do Sul, Brazil)

The acid mine-drainage (AMD), from the ecological point of view, affects the aquatic environments. The low pH and the high concentration of sulfates and dissolved metal ions reduce the biological diversity. These systems can be characterized as simple ecosystems, dominated by acidophilus and acid tolerant organisms. In the coal mining region of Santa Catarina, Brazil, the water streams impacted by AMD can be inhabited by few algae groups including the following genuses: *Microspora*, *Eunotia*, *Euglena*, *Mougeotia*, and *Frustulia*. The aim of this work was to study the

metal accumulation by these algae communities (periphyton) and their contribution in the water decontamination. The algae biofilms presents high concentrations of Fe, Al, Mn, and Zn onto the biomass. The results showed that is possible to associate the composition of the biofilms with the water chemistry and with the natural attenuation of AMD's environmental impact.

Thermodynamic modelling of concentrated sulphuric acid solutions
H. Sippola (Aalto University, Finland)

Acidic sulphate solutions are common is hydrometallurgy thus a proper thermodynamic model for aqueous sulphuric acid is essential, if the thermodynamic equilibrium calculation are utilized in the process development and modelling.

Existing Pitzer models for aqueous H_2SO_4 are either limited up to 6 molal (37w%) sulphuric acid solution or are too complicated for practical modelling purposes, with up to 8 model parameters, with over 30 terms fitted from experimental data within.

Recently, a modified Pitzer for concentrated solutions was developed in NPL,UK. The new model uses, instead of molalities, scaled mole fractions which will converge to molalities in dilute solutions. Thus, the model coincides with original Pitzer model at indefinite dilution.

The aim of this study is to the test the ability of the modified Pitzer equation to model concentrated sulphuric acid solutions using limited number of Pitzer parameters with a simple temperature dependency.

The conversion of celestite to $SrCO_3$ in ammoniacal solution containing ammonium carbonate/bicarbonate
M. Zoraga and C. Kahruman **(**Istanbul University, Turkey)

In this study, high-grade concentrate celestite ($SrSO_4$) has been converted into strontium carbonate in ammoniacal solution containing ammonium carbonate/bicarbonate. The effect of stirring rate, concentration, particle size and temperature on the dissolution rate was investigated. Fractional conversion was increased by increasing temperature and decreasing particle size, was decreased with increasing AC concentration and it was determined that stirring rate had no effect on the fractional conversion. The quantitative analysis of solution taken in a specified period of experiments was performed by ICP-OES. The SEM-EDS and XRD analysis were used for material characterization.

Investigating microbial colonisation in bioheaps with varying irrigation rate
R. Chiume, S. Minnaar, E. Ngoma and S.T.L. Harrison (University of Cape Town, South Africa)

Microbial colonisation plays an important role in mineral dissolution in heap bioleaching of low grade ore. To date, colonisation studies have focused on microbial attachment of single species to mineral concentrate under batch conditions, not representative of the heap leaching environments, with recent extension to flow systems. Contaminant hydrology and soil engineering investigations have indicated significant interactions between microbial colonisation and fluid flow in porous systems. Therefore, heap hydrology is expected to affect microbial colonisation through solution-ore and microbe-mineral contacting.

The influence of the irrigation rate on microbial colonisation was assessed using columns packed with acid agglomerated low grade copper-containing ore. The systems were inoculated via irrigation with iron and sulphur oxidising mesophilic microorganisms (10^{12} cells/ton ore), whilst operating under continuous flow conditions using three different application rates (2, 6 and 18 $L/m^2.hr$). The effluent solution was analysed daily for cell counts, pH, redox, ferrous, ferric, total iron and copper concentration. A novel in-bed sampling technique allowed for the extraction of ore samples at intervals during the leaching process to give insight into the microbial growth and the interstitial, weakly and strongly attached microbial population. The colonisation, growth rate and relative dominance of planktonic and attached populations are reported and related to leaching performance.

Bio-desorption of lithium isotope ($^7Li^+$) from a degraded lithiated mixed-bed ion-exchange resin using *Acidithiobacillus caldus*
M. Basitere, S.K.O. Ntwampe and M.S. Sheldon (Cape Peninsula University of Technology, South Africa)

The production of sulphuric acid was investigated in optimised aerated batch bioreactors, with *Acidithiobacillus caldus* (DSM 8584) using elemental sulphur as the source of energy. In these aerated batch bioreactors, sulphuric acid production of 0.4M was achieved over a period of 16 days. The sulphuric acid was concentrated to ~1M by evaporating 80% of moisture. The concentrated sulphuric acid was passed through a continuous ion-exchange packed-bed column containing a degraded lithiated mixed-bed resin to elute the lithium 7 isotope ($^7Li^+$) in the cation part of the mixed-bed resin. Desorption rates greater than 90% was achieved within 18 bed volume (BV) using the biologically produced sulphuric acid. Furthermore, a high desorption rate (>80%) was observed for the biological acid during the initial stage of 2 BV's compared to the commercial grade sulphuric acid, for which a desorption rate of 61% was achieved at the same stage. These results showed similar desorption rates of $^7Li^+$ to that of 1 M of mineral sulphuric acid. The use of the biological produced sulphuric acid showed an economic and effective method which could be considered in recovering valuable metals adsorbed on ion-exchange resin.

Separation of zirconium and hafnium using electrical field

A. Sadigzadeh, H. Shokri (Atomic Energy Organisation of Iran, Iran) and S.H. Tabaian (Amirkabir University of Technology, Iran)

In this work, a new method of separation of Hafnium and Zirconium is introduced in which, ions movement is facilitated and accelerated via an electric field. Extraction and separation of Hafnium from Zirconium is performed with TBP and D2EHPA extractants. In order to separate the two metals, two cells containing feed solution and recovery solution were utilized. Cells were connected to each other by the organic phase and the electric filed acted on them. Transmission of the ions occur trough the organic liquid membrane and under the applied electric field. The lower level of organic matter consumption and acceptable separation factor are the benefits of this method.

Results showed that the acceptable separation factor of 8.3 was achieved for Tri-butyl phosphate as the organic extractant.

TBP organic matter was found to be a stronger extractant compared to D2EHPA**.** Moreover, in addition to its higher extraction, it also revealed a better separation factor with respect to D2EHPA**.**

The effect of temperature and pH on the biosorption of heavy metals onto sea algae

Z.Harber (University of Stellenbosch, South Africa)

In the chemical and metallurgical industries heavy metal pollution give rise to major environmental concerns. Research has been conducted to study the viability of removing heavy metals from effluent water through the biosorption of the metals onto sea algae. Many types of sea algae have been tested and it was concluded that the brown sea algae, Ecklonia maxima, found on the west coast of South Africa, proves to be most effective biosorbent. The objectives are to investigate the effect of temperature and pH on the biosorption of Cu, Fe and Zn.

Based on the experiments done and the results analyzed, it was found that an increase in reaction temperature results in the increase of adsorption rate. Metals with higher atomic mass have higher adsorption rates. The optimum pH for acid pretreated solutions is 6 while the optimum pH for alkali pretreated solutions is 8. Also, the presence of additional metals in solution decreases the rate and the equilibrium end-point of the adsorption of a specific metal.