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- Renewables

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Transparency You Can See
Average circulation
(July – September 2014)
Paid: 17
Free: 3 687
Total: 3 704

Chemical Technology is endorsed by The South African Institution of Chemical Engineers



and the Southern African Association of Energy Efficiency



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A strategy for getting past the crossroad

by Carl Schonborn, PrEng, consulting editor, 'Chemical Technology'

The petrochemical industry and, by implication, the chemical and construction industries, seem to be at an impassable crossroad. The oil industry took one look at the oil price and decided this was tantamount to a catastrophe; meanwhile, oil refiners have racked up enormous profits in the first quarter of this year thanks to better refining margins. One hopes this will urge more spend where it is needed most, in clean fuels and emission controls. Maintenance of refineries is an ongoing practice and is a budget that cannot be tampered with too much.

However it is the large Capex projects such as clean fuels and expansions that are the lifeblood of the petrochemical contractors. The spin-off is enormous; all the other disciplines and those working in them, apart from process engineers, are dragged in to the loop, including environmental experts, civil engineers, geotechnical engineers, mechanical engineers, piping designers, construction engineers, electrical and instrumentation engineers, as well as a host of related suppliers to these disciplines.

Unfortunately, on the other side of the crossroad is a number of almost seemingly insurmountable problems, including a shortage of power, a labour force that is locked into the inflation spiral and looks to annual increases to maintain some semblance of a lifestyle, and additionally, a weak rand, which makes the imported cost of much-needed infrastructural equipment almost prohibitive.

What can possibly ease the transition across the crossroad? Government. Government is the only agent that can kickstart the industry, notwithstanding some of the legacy

issues that stand in its way. For example, the enormous capital costs of the two coal-fired power stations which are not only way behind their original schedules, but are consuming enormous amounts of money just to bring about a final completion/commissioning date.

Gas should have been part of the equation a long time ago, but is presently a long way off as South Africa just does not have the infrastructure to distribute gas, whether it be in the form of stranded gas in our neighbouring countries, offshore gas fields, shale gas in our southern provinces or Liquid Natural Gas, which is becoming a worldwide traded commodity, but needs significant infrastructure in the form of ports, regasification terminals and pipelines.

At the end of last year, the most welcomed decrease in the price of petrol and diesel would have been an ideal opportunity to start up the clean fuels refining strategy in South Africa, with probably a fairly modest tariff on the then fixed selling price. However, the fiscus spotted this windfall and it did not take long for a hefty tariff increase to appear, to be converted to Tax Revenue income for the Revenue Service.

It is imperative that the refiners start their clean fuels expenditure as soon as possible in order to reach the Euro V emission standards. Motor vehicles are being designed to operate on these fuel specifications, but if we wait too long, the cost of manufacturing a vehicle to operate on the current refined specifications will be prohibitive.

Gas is the energy of the future; clean fuels are now a necessity, not a luxury. Let the Strategy begin.

**Published monthly by:
Crown Publications cc**

Crown House
Cnr Theunis and
Sovereign Streets
Bedford Gardens 2007
PO Box 140
Bedfordview 2008
Tel: (011) 622-4770
Fax: (011) 615-6108

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Design & layout:
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(CUT-Zim)

Circulation:
Karen Smith

Publisher:
Karen Grant

Director:
J Warwick

Printed by:
Tandym Print - Cape Town

Is (over) regulation

stifling innovation?

by Janusz Luterek, PrEng

Over the past two decades, the South African government has, in the author's opinion, moved from the permissive regulatory environment of the past which fostered and nurtured innovation, to the restrictive regulatory environment such as that in Europe.

As a patent attorney I am faced daily with inventions which although great ideas, some of which have required a huge investment in time and resources, are faced with mountainous obstacles to commercialisation, not the least of which is the regulatory quagmire which is expanding on a regular basis as we join the highly, some may say overly, regulated countries of the world. Some have even referred to this way of governing as the "Nanny State" since government takes the view that the public needs to be protected not only from the perceived greed of corporations but also from their own bad choices.

So what are the obstacles faced by those who innovate and try to add to the pool of knowledge and hope also to benefit financially from their innovations?

Historically, South Africa had a legal framework conducive to innovation with laws and regulations in the main being drafted to define parameters outside which it would be illegal to operate. These parameters were usually quite general and allowed for a great degree of freedom within them to innovate and improve on the existing way in which things were done. There were noticeable exceptions to this philosophy where human health and well being was at issue, such as the Medicines and Related Substances Act and Regulations, which have always set a very high barrier to entry for innovation due to the nature of these products and their potential to harm the public in the long term. This was probably to some extent also due to the history of snake oil salesmen who would sell anything and make any claims regarding their snake oil to the desperate in order to 'make a quick buck'. However, in most other fields, the maxim was "That which is not explicitly forbidden is allowed", which was in fact very conducive to innovation, but placed an onus on innovators to be ethical in their innovation and to be concerned with the well being of the public and the environment, and not just of their pocket.

In continental Europe, however, the situation has been the opposite, with the maxim being "That which is not expressly allowed is forbidden" and, regrettably, in my opinion, the South African government has, over the last 20 years, moved from the permissive regulatory environment of the past which fostered and nurtured innovation, to the restrictive regulatory

environment such as that in Europe, which makes innovation very difficult and expensive.

This has also required the government which promulgated all the new and restrictive regulations, to institute programmes to re-ignite innovation and has invested vast sums to reprise a position which existed naturally prior to the change in policy from permissive to restrictive. Examples of such government initiatives include the founding of the Innovation Fund, the Innovation Hub, and the establishment of Technology Transfer Offices in all universities and parastatal research institutes. Although these initiatives must be praised, they shift innovation from the private lone wolf innovator to the institutional innovator who can navigate the regulatory seas with their innovation to bring it to fruition.

You may by now be asking yourself where this change from permissive to restrictive regulatory environments may be seen. The answer: these changes are pervasive throughout all spheres of life and include foodstuff regulation, agriculture, bioprospecting, mining, and even research itself!

As an example, in a drive to reap the benefits of the biodiversity in South Africa for all its people, the Biodiversity Act was promulgated together with its Bioprospecting, Access, and Benefit Sharing (BABS) regulations. To put things in perspective: historically, it was possible to bioprospect, ie, to search for plants, animals, and micro-organisms which may have some beneficial purpose, whether medicinal, agricultural, or industrial, and then to conduct further research on this and to protect any invention derived from it, such as active substances isolated from plants and/or micro-organisms, by way of a patent – without requiring any permission or even having to inform any government department of the research activities (with the exception of a patent application being filed).

Since the coming into effect of the Biodiversity Act and the BABS regulations, the situation has changed drastically and it is now a criminal offence to search for or identify any indigenous biological resource, such as a micro-organism, plant, or animal, without first obtaining a permit to do so from the Department of Environmental Affairs. Obtaining said permit is not a trivial procedure and it is challenging to





do so, to say the least, and would be very difficult for most small companies or lone innovators to do so.

However, this permit, the Discovery Phase permit, only permits the search for and indexing of the indigenous biological resource but not any further research or commercialisation thereof. In order to conduct further research or to commercialise any indigenous biological resource or a product thereof, a Commercialisation Phase permit must be obtained by each link in the chain of research and development and commercialisation thereof. This means that it is not simply a matter of obtaining a Commercialisation Phase permit by the party that discovered it under a Discovery Phase permit, but each research organisation, manufacturing entity, wholesaler, and so on, must have its own permit for the commercialisation of the indigenous biological resource.

To complicate matters further, the requirements for the obtaining of these permits are very onerous and, for example, require the identification of the indigenous people who may have been using said indigenous biological resource, entering into a benefit-sharing agreement with them, and the application to the Department of Environmental Affairs for a permit – all before any research or commercialisation can take place.

The result of the above regulatory environment on bioprospecting is that many small businesses are simply ignoring it and continuing illegally which puts them at risk of prosecution, but also prevents them from obtaining patent protection for their innovation, since the Patents Act requires that permits and benefit-sharing agreements be in place before a patent can be applied for. These smaller businesses, and some large ones, either are not aware of the onerous regulatory requirements or are simply unable to comply due to a lack of skills in dealing with such complexity which falls outside their core field of business.

Another example of how innovation is being stifled by regulation, is the Foodstuffs, Cosmetics, and Disinfectants Act which has numerous regulations associated with it, many of which are based on existing technology and entrench that which has already been approved, thereby making it very difficult to introduce new and innovative ingredients in food manufacture. The path to innovation is made more

tortuous not only by the existing regulations but also by the slow process of change in the regulations, for example, the Colourant regulations which prescribe which colourants may be used in foodstuffs in South Africa have not been updated comprehensively for about 20 years with the result that the table of permitted colourants does not include any natural colourants, with the absurd result that artificial colourants are permitted in your food but natural colourants, such as those produced by physical concentration processes of fruit and vegetables are not permitted. Thus, innovators who see a gap in the market and spend their time and effort to satisfy the demand are prevented from commercialising their innovative ideas, such as processes for producing natural colourants for foodstuffs, until the long and winding road of amending the Colourant regulations is finally completed.

Even in research the long red tape is there to trip up the unwary, for example, the Intellectual Property from Publicly Funded Research determines who owns any intellectual property which arises from co-operation with a publicly funded institution and thus the unwary innovator co-operating with a university may find at the end that he does not own the intellectual property in respect of his own innovation as under this law the university does!

It is a sad fact of our system that patent attorneys, although highly qualified by being required to hold both a degree in science or engineering and a law degree and to pass many qualifying examinations before being admitted to practice, are not trained in understanding and assisting their clients in overcoming the regulatory hurdles which stifle innovation and which to the writer is just as important as protecting the invention if the innovator is to be able to commercialise and monetise the innovation.

Having identified this gap of the approaching regulatory tsunami and its effect on innovation, the author has set up a team at Hahn & Hahn which is able to assist its clients in understanding and overcoming the regulatory hurdles. If you are an innovator who is experiencing these frustrations, then remember to contact the writer (on janusz@hahn.co.za or www.hahn.co.za). to help you navigate the regulatory maze and to protect your innovations and inventions.

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Removal of copper from wastewater by cementation from simulated leach liquors

by Ehssan Nassef, Department of Petrochemical Engineering, Faculty of Engineering, Pharos University, Alexandria, Egypt and Yehia A El-Taweel, Department of Chemical Engineering, Faculty of Engineering, Alexandria University, Alexandria, Egypt

This article is concerned with the study of copper cementation in batch reactors containing rotating iron cylinders. Copper has been selected for two reasons: removal of toxic metals whose effects on the environment have been clearly proven and the fact that copper is a valuable saleable product. Iron has been chosen as a sacrificial metal because of its availability and its low cost .



Abstract

Every year, tons of precious and/or toxic metals are thrown away in industrial liquid effluents and most frequently directly into the natural environment. The recovery of those metals in dilute solutions is an everyday problem associating both ecology and economy. Copper is among the most prevalent and valuable metals used by industry. Cementation is one of the most effective and economic techniques for recovering toxic and or valuable metals from industrial waste solutions and from leach liquors obtained by leaching low grade copper ore. The present study was carried out to investigate the removal of copper metal ions from synthetic wastewater by cementation using a rotating iron cylinder. The study covered the effect of different parameters in batch mode which are: Initial copper concentrations, pH values, rotational speed, and reaction temperature on the rate of cementation. The rate of cementation was found to increase with increasing rotational speed, temperature, and pH till a value of 2,1 and then starts to decrease. On the other hand, as the initial copper ions concentration increases from 0,2 to 0,4 M, the rate of copper ions' removal increases. The rate of copper recovery ranged from 10 % to 90 % per hour depending on the operating conditions. Rates of cementation which can be expressed in terms of the rate of mass transfer were correlated to the controlling parameters by dimensionless equation: $Sh=0.18 SC^{0.33} Re^{0.961}$. This equation can be used in the design and operation of high-productivity cementation reactors.

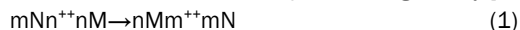
The importance of environmental pollution control has increased significantly in recent years. Environmental lists are primarily concerned with the presence of heavy metals in aqueous effluents due to their high toxicity and impact on human and aquatic life [1]. Copper, which is very detrimental for both, can be found in many wastewater sources including printed circuit board manufacturing, metal finishing processes, eg, pickling of copper and its al-

loys, electroplating and electroless plating, electro polishing, paint manufacturing, wood preservatives and printing operations [2]. A number of technologies has been developed over the years to remove copper from wastewater. The most important of these technologies include adsorption [3], chemical precipitation [4], ion exchange [5], reverse osmosis [6] and electrodialysis [7], but all of them have drawbacks. Cementation is one of the most effective and economic



techniques for recovering toxic and/or valuable metals from industrial waste solutions [8]. The process has been largely used in industry for a long time, not only in hydrometallurgy but also in the purification process of stream and waste waters [9]. Cementation as a method has some advantages, such as recovery of metals in relatively pure metallic form, simple control requirements, low energy consumption and has a generally low cost process. The main disadvantages of the technique are excess sacrificial metal consumption [10].

Cementation is used as a general term to describe the process whereby a metal is precipitated from a solution of its salts by another electropositive metal by spontaneous electrochemical reduction to its elemental metallic state, with consequent oxidation of a sacrificial metal for the recovery of more expensive and more noble dissolved metal species present in aqueous solutions [11]. The general reaction for a cementation process is given by [12]



- where N represents the noble metal
- and M the reductant metal.

This process has been applied in metallurgy, to recover metals from dilute leach liquors [13-18]. It is also exploited in the metal finishing industry to recover noble metals such as copper from some waste solutions, etc.

This article is concerned with the study of copper cementation in batch reactors containing rotating iron cylinders. Copper was selected for two reasons: removal of toxic metals whose effects on the environment have been clearly proven, beside the fact that copper is a valuable saleable product. Iron has been chosen as a sacrificial metal because of its availability and its low cost. In addition the present technique is used to recover copper from leach liquors obtained from low grade copper ores. Since copper cementation on less noble metal is a diffusion controlled process [19], the aim of the present work is to enhance the rate of cementation of copper on iron by using a rotating iron cylinder.

The rate of the copper (II)/iron cementation reaction in the presence of surfactant – determined by measuring the rate of cementation of copper on a rotating iron cylinder from a copper sulphate solution in the absence and the presence of surfactant – was investigated by El-Batouti [19] who reported that the rate of cementation reaction is decreased by an increasing concentration of surfactant, temperature and number of rotations. Sulka *et al* [20] who studied the kinetics of the cementation of silver ions onto copper from acidic sulphate solutions in a rotating cylinder system reported that the rotational speed leads to a considerable increase in the rate of cementation.

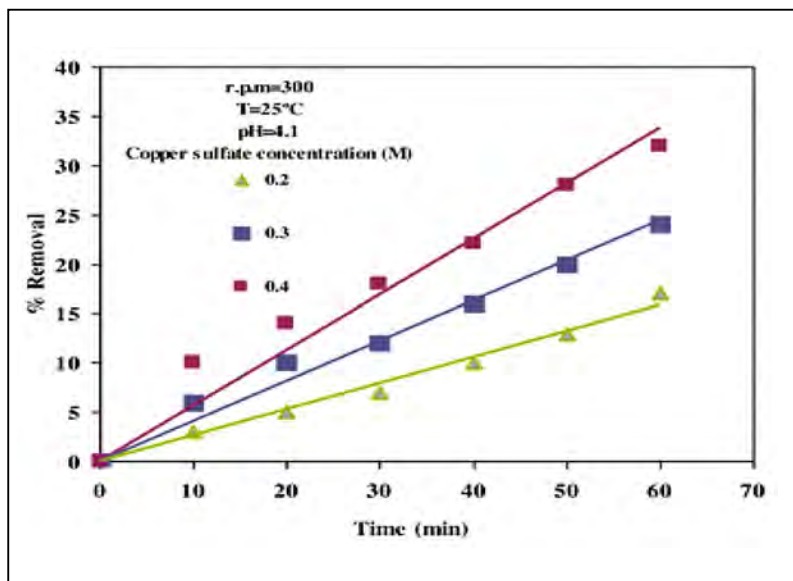
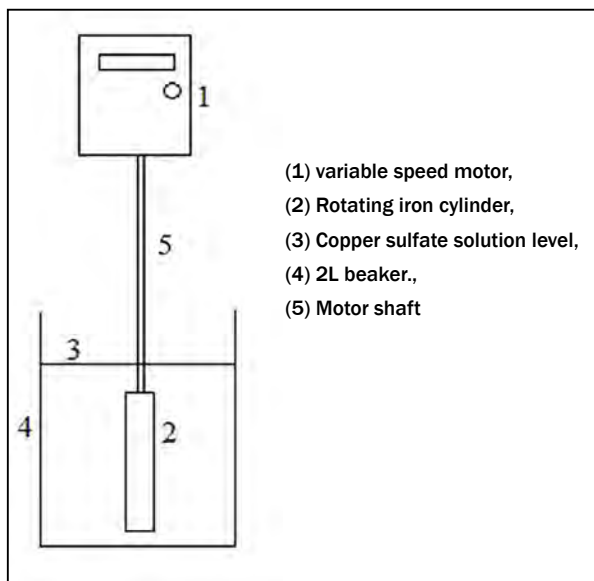


Figure 1: Schematic diagram of the experimental set-up

Figure 2: Effect of cementation time on the percentage removal of different copper sulfate concentrations

Previous studies on Cu cementation have dealt with wastewater which contains low Cu^{++} concentration [20, 21]. The present work deals with solutions containing relatively high Cu^{++} concentrations such as those obtained by leaching low grade copper ores or exhausted copper oxide catalyst. High Cu^{++} concentrations differ from dilute solution in their tendency for interionic attraction which affects properties such as electrical conductivity, diffusivity and ion activity [22]. In addition high Cu^{++} concentrations cause the formation of rough deposits which alters the hydrodynamics of rotating cylinders [23-26].

Experimental set up

The experimental set-up is schematically shown in Figure 1. It consists of a 2 l beaker and a rotating iron cylinder of 10 cm length and 2 cm diameter that was positioned in the centre of the beaker at a distance equal to 2 cm from the beaker. An iron cylinder was connected to a multi speed agitated motor and was insulated with teflon.

Before each run a stock solution of copper sulfate was prepared by dissolving the copper sulfate analytical reagent in distilled water. The experimental desired concentrations were obtained by successive dilutions with distilled water. The pH of the solution was adjusted by adding 0,1N hydrochloric acid solution each experiment. The pH- meter (Hana, Model pH211) was used to measure the pH of the solutions. The analytical determination of copper sulfate solutions was carried out by iodometry using a standard solution of sodium thiosulfate [27].

Experimental procedure

Copper solutions were prepared from the stock solution by successive dilution to the desired concentrations. In each run 1 750 ml of synthetic solution was put in the reactor cell. The pH of the solutions was adjusted by adding 0,1 N hydrochloric acid solutions for each experiment. Before each run cylinder rotation speed was adjusted at the required value, and rotation speed was measured by an optical tachometer.

During experiments, 10 ml samples were collected every 10 minutes from a fixed location and analysed for the percentage removal of copper ions. The rate of copper removal was determined under different parameters. The physical properties of copper sulfate solution such as density and viscosity were measured experimentally using a density bottle and Ostwald viscometer; whereas the diffusivity was calculated from literature [28].

Results and discussion

Effect of time

The effect of initial copper concentration on the rate of cementation was studied using 0,2, 0,3 and 0,4 M of copper ions (Figure 2). The data were assumed to fit the equation [29]:

$$V \ln(C_0/C) = KAt \quad (2)$$

Where:

- V Volume of solution containing copper ions (cm^3),
- C_0 Initial concentration of copper ions (M),
- C Concentration of copper ions at time t (M),
- K Mass transfer coefficient for the smooth cylinder
- A Active surface area of the rotating iron cylinder (cm^2), and
- t Time (s).

The mass transfer coefficient of copper cementation on iron (k) was calculated from the slope (kA/V) of the plot $\ln C_0/C$ vs t. It is clear from Figure 2 that as the initial copper ions concentration increases from 0,2 to 0,3 M the percentage removal increases. According to the electrochemical theory of cementation which postulates that cementation takes place through the galvanic cell: Fe/ electrolyte/ Cu, increasing the cathode area via copper powder formation would decrease polarization and consequently would increase the rate of cementation. This phenomenon was also observed by AH Elshazly [30] in the case of copper cementation onto zinc plates. Figure 3 shows that the present data fit equation (2), ie, the reaction is first order with respect to Cu^{++} concentration. This finding is consistent with previous studies [20,21] on extremely dilute solutions, ie, the concentration range of Cu^{++} does not alter the mechanism of the reaction.

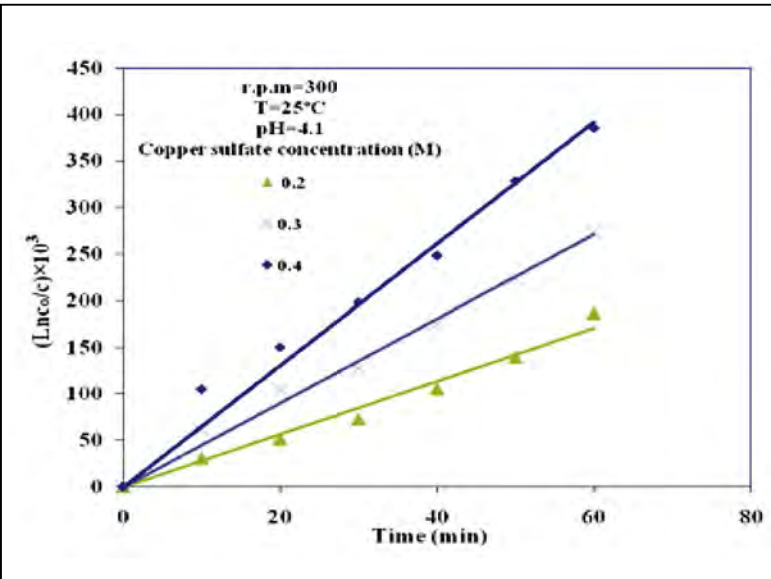


Figure 3: $\ln(C_0/C_t)$ vs. cementation time at different copper sulfate concentrations

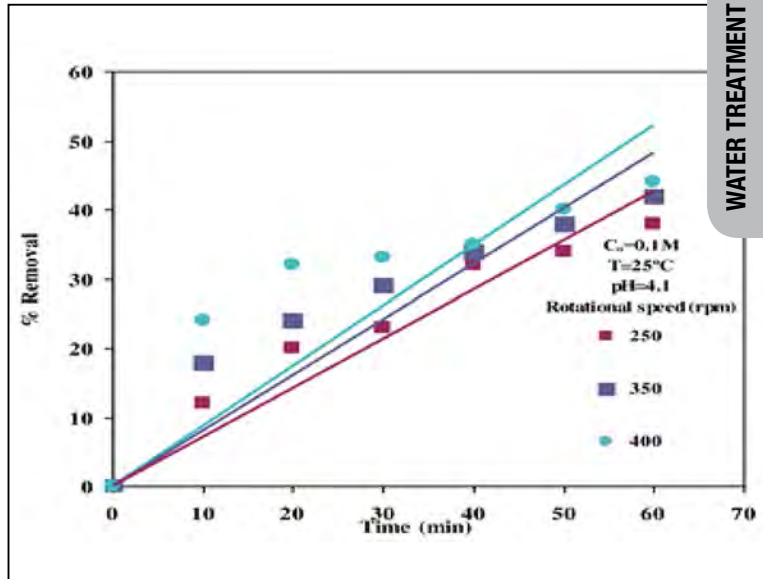


Figure 4: Effect of rotational speed on the percentage removal of copper ions

Effect of rotational speed

Figure 4 shows the effect of cylindrical rotation speed on the rate of cementation the mass transfer coefficient under different initial concentrations of Cu^{++} which was calculated from the slope (KA/V) of the plot. $\ln C_0/C$ vs t , the mass transfer coefficient under different initial concentrations of copper ions was calculated. The effect of rotational speed on the rate of reaction can be used to determine whether a reaction is diffusion or chemically controlled. If the rate of reaction increases with increasing the rotational speed, then the reaction is diffusion controlled. If the rate of the reaction is independent of the rotational speed, then the reaction is completely chemically controlled [20]. The diffusion controlled nature of the reaction was confirmed by the fact that the mass transfer coefficient increases systematically with increasing the speed of rotation, from 200 to 400, as shown in Figure 4. The 400 rpm seems to be the optimum rotational speed, but 350 is better to save the power. Increasing the speed of rotation reduces the diffusion layer thickness across which copper has to diffuse to reach the iron surface with a consequent increase in the rate of copper ions deposition. This phenomenon was also observed by S A Nosier [31] in the case of cadmium cementation onto a cylindrical zinc sheet.

Effect of initial pH of the solution

It has been established that pH is an important operating factor influencing the performance of a cementation process. In this work, the examination of the pH effect on the cementation process was studied for pH ranging from 1,1 to 4,1. Copper cementation onto iron substrate in an acid medium is accompanied by the simultaneous iron dissolution in acid that produces hydrogen and implies an over-consumption of iron. The generated hydrogen bubbles increases local turbulence which enhances the rate of mass transfer [32]. So, from Figures 6 and 7, it was observed that the mass transfer coefficient and the rate of cementation increases slightly from pH 1,1 to 2,1. However, for pH higher than 2,1, ferric hydroxide is produced, blocking the active surface and leading to more significant decrease of k value

and the rate of cementation [33]. Therefore, a copper sulfate solution of pH= 2,1 is the optimum value.

Effect of temperature

It has been found in many studies reported previously that the effect of temperature onto cementation reactions is significant. The variation of $\ln(C_0/C)$ with cementation time t showing the effect of temperature (ranging from 25 to 55 °C) is presented in Figure 8. The values of the cementation rate constant k , calculated from the slopes of the curves by using Eq. (2). It can be seen from these results that the cementation rate increased greatly with the increase of temperature from 25 to 55 °C. This last value of temperature seems to be the optimal one. The increase in the rate of cementation with temperature may be attributed to the increase in the diffusivity (D) of Cu^{++} across the concentration boundary layer surrounding the rotating cylinder as a result of decreasing the solution viscosity (μ) according to the Stokes- Einstein equation [34]

$$\frac{\mu D}{T} = \text{constant} \quad (3)$$

From Figure 10, according to Arrhenius equation:
 $K = A \exp(-E/RT)$ (4)

Where:

- E is the activation energy (kcal/mole),
- R is the universal gas constant (cal/mole.°k).
- A is the frequency factor and
- T is the Kelvin temperature, we found that the value of the activation energy is 4,556.

So, we can deduce that the reaction between the solution and the rotating cylinder is a diffusion controlled reaction.

The following dimensionless mass transfer equation was found to correlate the mass transfer coefficient to these variables:

$$Sh = 0.18Sc^{0.33}Re^{0.961} \quad (5)$$

Where:

- Re is the Reynolds number ($= \rho n v d^2 / \mu$),
- Sc is the Schmidt number ($\mu / \rho D$),
- Sh is the Sherwood number (Kd/D),

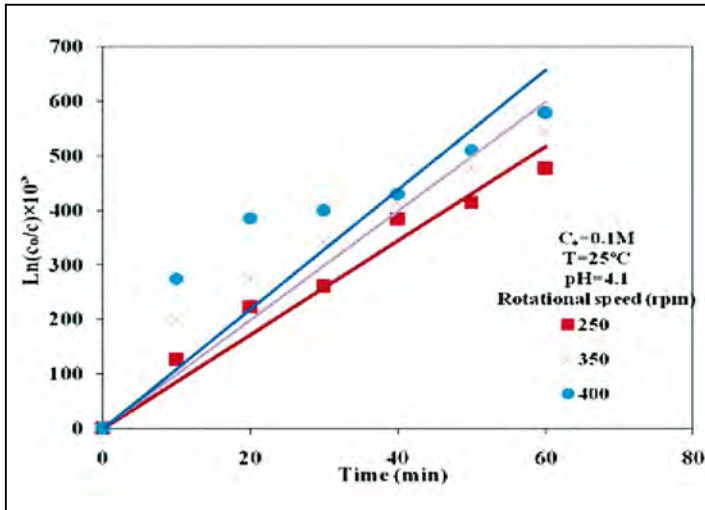


Figure 5: $\ln(C_0/C_t)$ vs. time at different rotational speeds

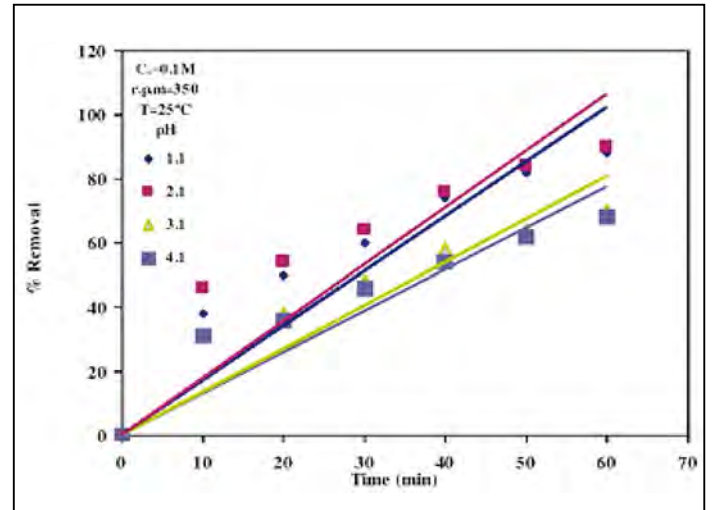


Figure 6: Effect of pH on the percentage removal of copper ions

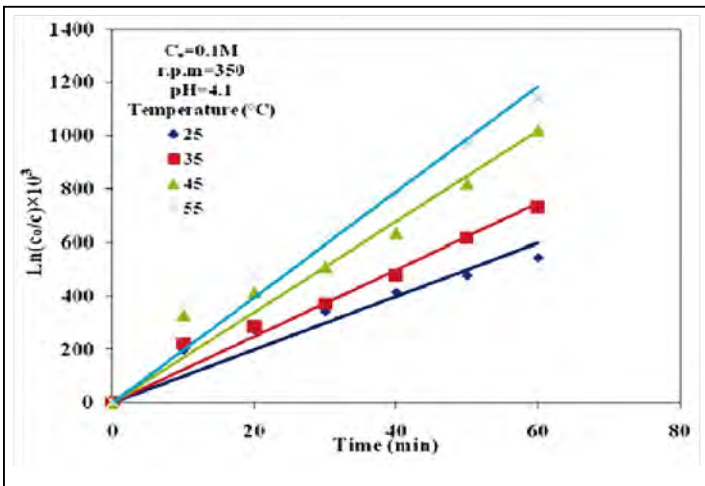


Figure 9: $\ln(C_0/C_t)$ vs. time at different temperatures

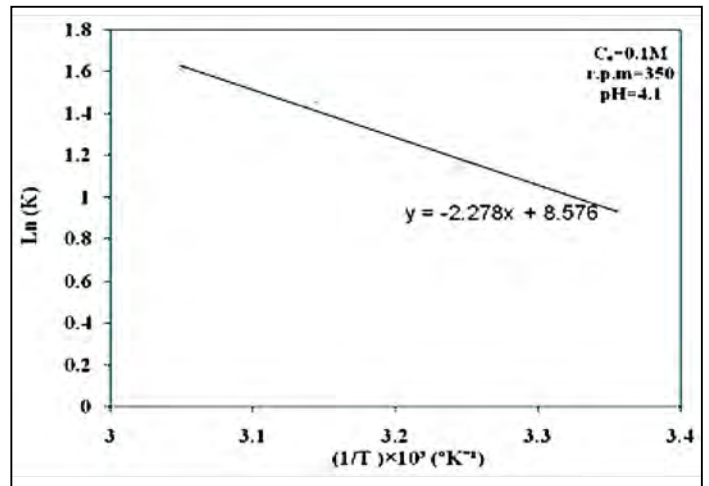


Figure 10: $\ln(K)$ vs. $(1/T) \times 10^3$ at different temperatures

The present study is concerned with cementation of copper from a relatively high concentration of CuSO_4 , similar to solutions obtained by leaching low grade ores and exhausted copper oxide catalyst on the rotating iron cylinder. This design offers high copper ions removal rates owing to the high degree of turbulence prevailing at the surface of the rotating cylinder even at a low speed of rotation.

- d is the iron electrode diameter (m),
- D is the copper iron diffusivity ($\text{m}^2 \cdot \text{s}^{-1}$),
- v is the rotation per second (Rps),
- μ is the absolute viscosity ($\text{Kg} \cdot \text{m}^{-1} \cdot \text{s}^{-1}$) and
- ρ is the density of solution ($\text{Kg} \cdot \text{m}^{-3}$).

The exponent of Sc was fixed at 0,33 following previous theoretical and experimental studies in mass transfer. The exponent 0,961 was obtained by plotting $\log Sh$ versus $\log Re$ (Figure 11), for the conditions: $1166 < Re < 5840$, $Sc = 1744$ 35. The value 0,18 was obtained by a Sh versus $Sc^{0.33} \times Re^{0.961}$ (Figure 12). Previous studies on mass transfer at rotating cylinders [23] have shown that for smooth rotating cylinders Sh increases with 0,7 power of Re . The exponent 0,96 obtained in this work may be attributed to the surface roughness induced by the deposited copper [23-26]. The above equation can be used in the design and operation of high-productivity cementation reactors.

Conclusion

The majority of previous studies on cementation have dealt with extremely dilute solutions typical of waste water. The present study is concerned with cementation of copper from a relatively high concentration of CuSO_4 similar to solutions

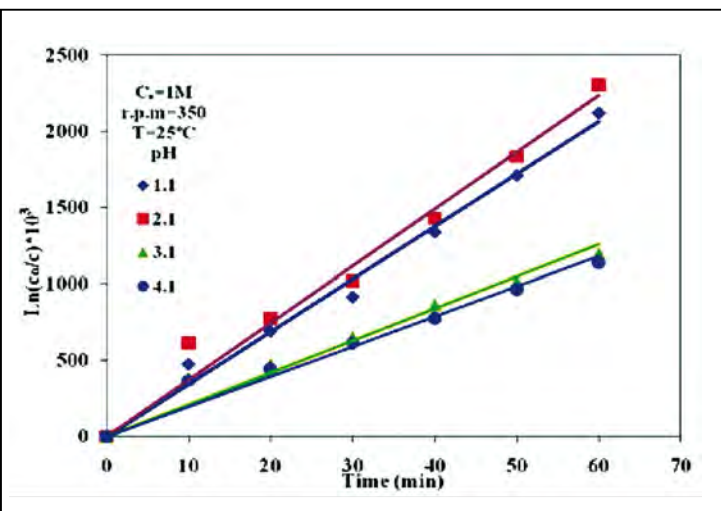


Figure 7: $\ln(C_o/C_t)$ vs. time at different initial pH of the solution

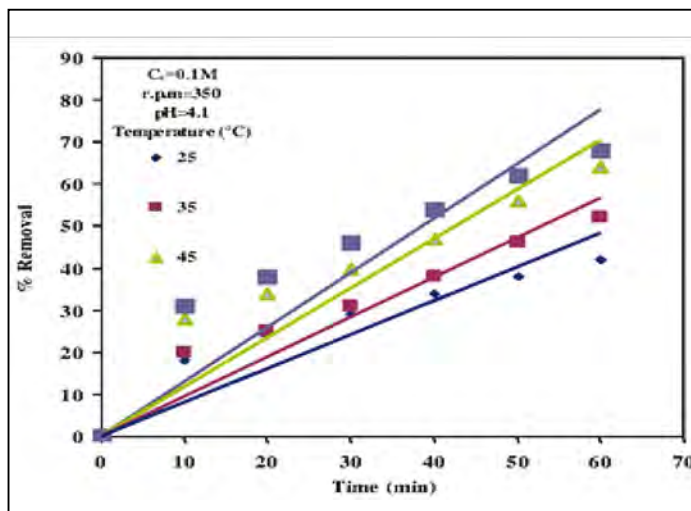


Figure 8: Effect of temperature on the percentage removal of copper ions

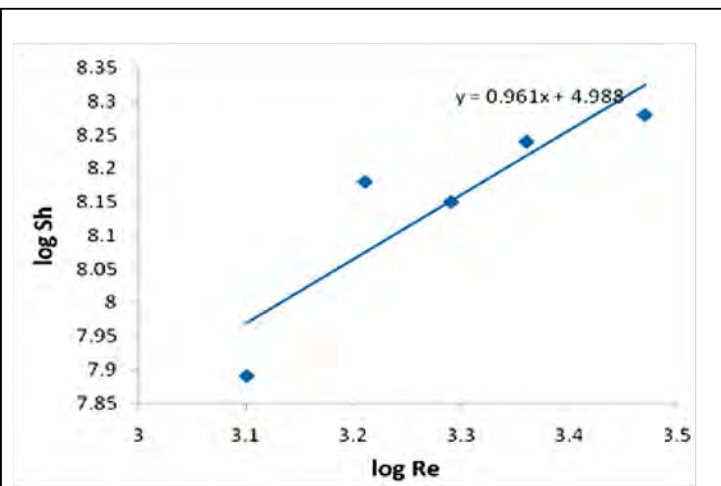


Figure 11: $\log Re$ and $\log Sh$ ($C_o = 0.1 M$)

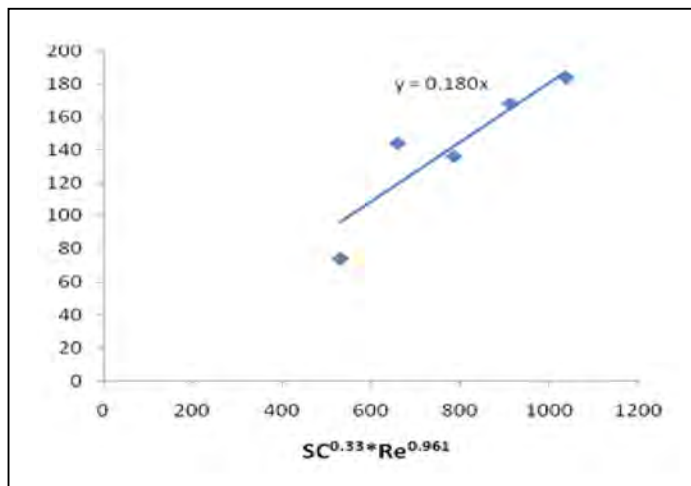


Figure 12: Sh and $SC^{0.33} * Re^{0.961}$ ($C_o = 0.1 M$)

obtained by leaching low grade ores and exhausted copper oxide catalyst on the rotating iron cylinder. This design offers high copper ions removal rates owing to the high degree of turbulence prevailing at the surface of the rotating cylinder even at a low speed of rotation. The influence of variables such as cylinder rotational speed, initial metal ion concentration, initial pH of the solution and temperature were investigated. The results showed that the rate of copper removal increases with increasing rotational speed and temperature. It was also observed that as the initial copper concentration increases from 0,2 to 0,4 M the rate of copper ions removal increases.

Another point worth mentioning is that the copper ions removal rate increases with increasing pH till a value of 2 and then starts to decrease. The optimum conditions for the cementation process by using the present cell based on maximum copper ions removal was rotational speed of 350 rpm, 55 °C, pH of 2,1 and 0,2 M of copper ions. The rate of Cu recovery ranged from 0 % to 90 % per hour depending on the operating conditions.

List of Symbols

N: the noble metal; M: the reductant metal; K: Mass transfer

coefficient for the smooth cylinder; d: Iron electrode diameter (m); D: Copper iron diffusivity ($m \cdot s^{-1}$); v: Rotation per second (Rps); Re: Reynolds number ($=\rho v d / \mu$); Sc: Schmidt number ($=\mu / \rho D$); Sh: Sherwood number ($=K d / D$); V: Volume of solution containing copper ions (cm^3); C: Concentration of copper ions (M); C_o : Initial concentration of copper ions (M); A: Active surface area of the rotating iron cylinder (cm^2), t: Time(s), E: the activation energy (kcal/mole), R: the universal gas constant ($cal/mole \cdot ^\circ K$) A: the frequency factor, T: the Kelvin temperature ($^\circ K$).

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A list of references for this article is available from the editor at chemtech@crowm.co.za.

This article was first published in J ChemEng Process Technol Volume 6 • Issue 1 • 1000214, ISSN: 2157-7048 JCEPT, an open access journal, Authors Nassef E, El-Taweel YA (2015), Removal of Copper From Wastewater By Cementation From Simulated Leach Liquors doi:10.4172/2157-7048.1000214

New solutions needed to recycle fracking water

by Mike Williams and David Ruth, Rice University, Houston, Texas, USA

Rice University scientists have performed a detailed analysis of water produced by hydraulic fracturing (aka fracking) of three gas reservoirs and suggested environmentally friendly remedies are needed to treat and reuse it.

Rice University researchers performed a detailed analysis of 'produced' water from three underground shale gas formations subject to hydraulic fracturing. The accompanying chart shows the amounts of total carbon (TC), nonpurgeable organic carbon (NPOC) and total inorganic carbon (TIC) in the samples. More advanced recycling rather than disposal of 'produced' water pumped back out of wells could calm fears of accidental spillage and save millions of gallons of fresh water a year, said Rice chemist, Andrew Barron, leader of the study that was published in the Royal Society of Chemistry journal 'Environmental Science: Processes and Impacts'.

The amount of water used by Texas drillers for fracking may only be 1,5 percent of that used by farming and municipalities, but it still amounts to as much as 5,6 million gallons a year for the Texas portion of the Haynesville formation and 2,8 million gallons for Eagle Ford. That, Barron said, can place a considerable burden on nearby communities.

Barron noted that shale gas wells, the focus of the new study, make most of their water within the first few weeks of production. After that, a few barrels a day are commonly produced.

The project began with chemical analysis of fracking fluids pumped through gas-producing shale formations in Texas, Pennsylvania and New Mexico. Barron and the study's lead author, Rice alumnus, Samuel Maguire-Boyle, found that shale oil and gas-produced water does not contain significant amounts of the polyaromatic hydrocarbons that could pose health hazards; but minute amounts of other chemical compounds led them to believe the industry

would be wise to focus its efforts on developing nonchemical treatments for fracking and produced water.

Currently, fracturing fluid pumped into a well bore to loosen gas and oil from shale is either directed toward closed fluid-capture systems when it comes out or is sent back into the ground for storage. But neither strategy is an effective long-term solution, Barron said. "Ultimately, it will be necessary to clean produced water for reuse in fracking," he said. "In addition, there is the potential to recover the fraction of hydrocarbon in the produced water."

Fracking fluid is 90 % water, Barron said. Eight to nine percent of the fluid contains sand or ceramic proppant particles that wedge themselves into tiny fractures in the rock, holding open paths for gas and oil to escape to the production well.

The remaining 1 or 2 percent, however, may contain salts, friction reducers, scale inhibitors, biocides, gelling agents, gel breakers and organic and inorganic acids. The organic molecules either occur naturally or are a residue from the added components.

The researchers found most of the salt, organic and other minerals that appear in produced water from shale gas reservoirs originate in the connate waters trapped in the dense rock over geologic time scales. These should be of little concern, they wrote. But they also found that produced water contained potentially toxic chlorocarbons and organobromides, probably formed from interactions between high levels of bacteria in the water and salts or chemical treatments used in fracking fluids.

Barron said industry sometimes uses chlorine dioxide





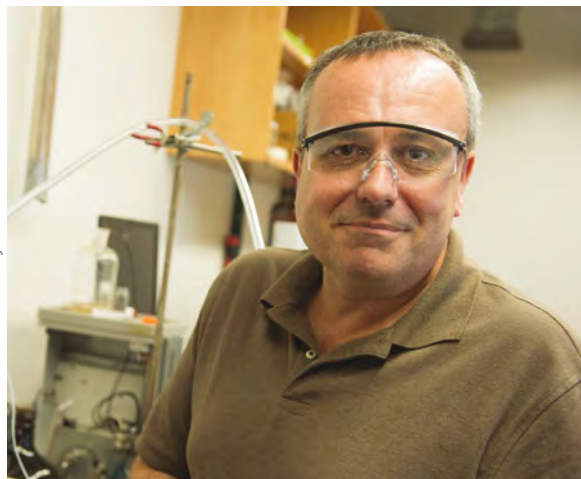
or hypochlorite treatments to recycle produced water for reuse, but these treatments can actually enhance bacteria's ability to convert naturally occurring hydrocarbons to chlorocarbons and organobromides. The researchers suggested this transition could happen either downhole or in storage ponds where produced water is treated.

"We believe the industry needs to investigate alternative, nonchemical treatments to avoid the formation of compounds that don't occur in nature," Barron said. Primarily, he said, the researchers want their analysis to anticipate future problems as industry develops processes to remove organic compounds from water bound for reuse.

He continued, saying that the new paper should be of particular interest to international producers who are preparing to ramp up gas-recovery efforts in the United Kingdom, which recently announced plans to expand drilling, and other European countries. "As the UK and other European countries are looking to start hydraulic fracturing, it is important that they adopt best practices at the start, as opposed to evolving over time, as it has occurred here in the United States," he said.

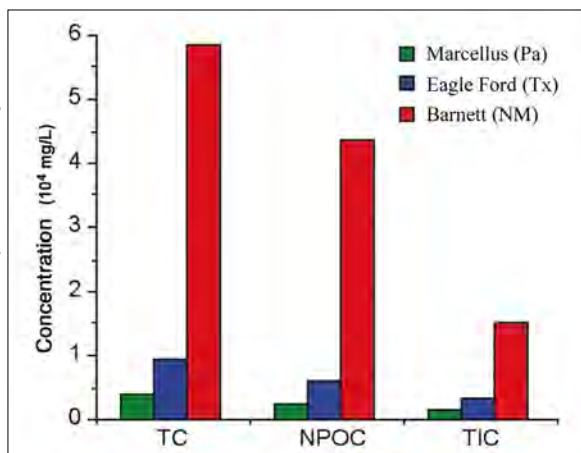
The Robert A Welch Foundation and the Welsh Government Sêr Cymru Program funded the research. Barron is Rice's Charles W Duncan Jr.-Welch Professor of Chemistry and a professor of materials science and nanoengineering.

This article was first published on the Rice University News site in August 2014 and is republished here with kind permission



Jeff Fitlow/Rice University

Rice University chemist Andrew Barron led an analysis of water produced by hydraulic fracturing of three gas reservoirs and suggested environmentally friendly remedies are needed to treat and reuse it.



Barron Research Group/Rice University

The chart shows the amounts of total carbon (TC), nonpurgeable organic carbon (NPOC) and total inorganic carbon (TIC) in the samples.

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Veolia stays on-site to reduce costs for Evander Gold Mine

Veolia Water Technologies South Africa has assumed the day-to-day chemical supply and services of the on-site water treatment for Evander Gold Mining in Mpumalanga. After a recent review report, four months into the three-year agreement, Veolia has already improved substantially on past practices and increased efficiency while reducing overall water treatment costs for the mine.

Veolia embarked on this total water management agreement in November last year following a full site survey on Pan African Resources, Evander Gold Mining MET Plant as well as 7 and 8 shaft. This survey revealed that large parts of the water circuits were not being treated by any chemicals due to faulty dosing stations while other parts of the circuits were facing dangerous chemical spillages where dosing station pumps had broken. As a result, highly corrosive water and scale were flowing through the above and below ground water circuits, decreasing the mine's cooling and ventilation efficiency while damaging its equipment.

"We opted for a full operation and maintenance agreement with Evander Gold Mine, where we will manage the entire water treatment system. As part of the agreement, a Veolia specialist will remain on-site for the duration of the contract, providing 24/7 technical direction, support and consultancy," says Carl van Heerden, Hydrex Industrial Manager, Veolia Water Technologies South Africa.

As part of this agreement, Veolia supplied 12 new treatment solutions, including: new chemical dosing stations; flocculants, coagulants, anti-scalant and micro-biocide chemical treatment; a semi-automated duplex flocculant plant; and coagulant plants to address the water treatment problems. Veolia also supplied its range of Hydrex™ chemicals at a variable fee after a weekly stock-take – meaning the mine will ultimately only pay for chemicals it has used.

Since the revised treatment plan was implemented, Junior Sales Consultant Pieter Jacobs, together with van Heerden, have managed and monitored the mine's water treatment progress through weekly water analyses and reports. Results recently detailed in the four-month review of the programme show that the new treatment regime is not only out-performing compared to specification; it is also saving the mine money through a much more efficient operation.

Due to the bad state of the circuit's settlers at shaft 8, Veolia commenced treatment using gel blocks and added a



Veolia installed spill-proof and accurate chemical dosing stations around the mine.



Veolia designed and installed 12 new treatment stations situated above ground and 1,8 km below ground that increased the mine's overall efficiency.

Hydrex™ 3936 coagulant. This dual treatment programme saw immediate positive results: the turbidity and Total Suspended Solids (TSS) levels were reduced by 45 % on settler 1 and 37 % on settler 2. Furthermore, the duplex flocculant and coagulant plants have resulted in a further turbidity reduction of 27 % on settler 1 and 48 % on settler 2 allowing for proper dosing control while optimising the treatment programme. In addition, all old non-functional dosing stations at the fridge plant were replaced with new dosing stations, drastically improving iron and Total Dissolved Solids (TDS) concentrations.

At shaft 7, Veolia installed a new coagulant dosing station that employs a custom-designed chemical treatment programme consisting of Hydrex™ 6611 and Hydrex™ 3936. This new treatment programme has resulted in a reduction of turbidity levels of 32 % and overall settler efficiency improvement from 90 % to 98 %.

Two new dosing stations were also installed along with the condenser, main compressor cooling tower and spray pond. These stations utilised Hydrex™ 2204 and Hydrex™ 7761 chemicals, which again im-

proved the overall iron and TDS concentrations as well as a visible reduction of algae.

"The improvement of the water quality on the settlers benefits the entire water circuit. Overall TDS and iron concentrations are down, the circuits require fewer chemicals each month and the equipment gets closer to spec – ultimately running more efficiently and lowering overall maintenance costs," comments van Heerden. "We also worked around the clock, 7 days-a-week to install new equipment in just 30 days – half the expected time – and installation was relatively seamless considering we were adding and removing equipment so far below ground."

Owing to the early success of this agreement, Veolia is currently in negotiations with Evander Gold Mining to expand its outsourced agreements locally as well as within Pan African Resources' other mines throughout southern Africa.

For more information contact:

Carl van Heerden, Hydrex Industrial manager, on tel: +27 11 974 8161, or email carl.vanheerden@veoliawaterst.co.za



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Resourcing the world



Bioprocess specialist works towards relevant biotechnology products

CSIR chief scientist Dr Raj Laloo is leading the commercialisation of a range of novel, eco-friendly biotechnology products for the treatment of waste water, aquaculture and agriculture. OptimusBio, a company created from within the CSIR using a technology platform developed by Laloo and his team, is expected to spin out of the CSIR within the next year or two to manufacture these products. Laloo is a specialist in the field of bioprocess and product development. He has a wealth of experience, having spent over 15 years in research and development laboratories, pilot-scale operations and full-blown commercial manufacturing.

Working towards this spin-out was not a natural choice for Laloo, but one he does feel passionate about. It was, in fact, born out of his passion to see his life's work having relevance. "What I do in terms of research and development is not influenced by my personal preferences but rather my personal passion," says Laloo. He is as passionate about doing work that has a real impact, as he is about developing people. His career has always been about changing lives, educating people and preparing them for real-world industry needs. He has trained

more than 50 students at different levels for both academia and industry. Laloo places equal value on a student with a PhD qualification and those with lower qualifications but who have practical skills. He believes that qualifications and practical work experience play an equally crucial role.

Laloo's passion for training people is driven by his desire to make an impact. In the course of developing biotechnology platforms and technologies that address challenges of developing countries, he trains people to carry the work forward, both in research and in the scientific industry.

When asked how his decision came about to lead the OptimusBio spin-out, he says he could not risk an amazing technology with great potential for impacting people's lives and the environment, become irrelevant. "I realised that I either had to find someone reliable to commercialise the technology platform and take it into the real world where it would have value and make a contribution, or I had to do it myself," he says. Laloo's expertise includes process development, process intensification, process integration and technology management. He has worked on several projects to stimu-

late the local biotechnology industry and leads this national agenda on behalf of the CSIR. He has an excellent track record in securing funding for biotechnology products and processes. He is a reviewer and advisor for several local and international organisations and journals, has written more than 200 research reports, five publications, 25 conference papers, two patents and three scientific book chapters. Most important to Laloo, is his development of some 20 technologies that have been commercialised, with an annual revenue of around R200 million, creating 860 jobs. This is what he believes epitomises his achievements as a researcher. Before joining the CSIR in 2000, Laloo worked at AECI Bioproducts where he was part of a team that built what, at the time was the Southern hemisphere's biggest fermentation production facility, from scratch. He completed his PhD in process engineering through Stellenbosch University in 2010.

For more information contact Tendani Tsedu, Media Relations Manager, Council for Scientific and Industrial Research on tel: +27 12 841 3417.

A safe and environmentally-sustainable treatment solution for alkaline wastewater control

For more than 30 years, SOLVOCARB® has been recognised as a leading solution in neutralising alkaline wastewater in order to ensure effective pH control. Afrox applications engineer Gareth Jones reveals that this proven solution is now more important than ever, given the consistent implementation of stricter controls to protect the environment from harmful chemicals, by ensuring municipal wastewater treatment plants are not compromised by high pH discharges.

"SOLVOCARB® ensures that wastewater discharged into sewage outlets and other watercourses is within a narrow pH range around the neutral point. When dissolved in water, recycled CO₂ gas forms a mild and safe carbonic acid that reduces the pH value to the appropriate level," he explains.

SOLVOCARB® injects CO₂ via a diffuser hose, reactor or nozzle. In each application, it ensures the appropriate process for neutralising alkaline wastewater and process waters, with mobile or stationary equipment options designed for use in treatment plants, equalising tanks or pressurised transfer or recycle pipework.

Jones adds that, unlike mineral acids, CO₂ is not categorised as a substance that is harmful to natural waters. "The carbonic acid derived from CO₂ creates no excessive accumulations of unwanted anions such as

chlorides or sulphates, thereby eliminating the risk of corrosion of the system components. A flat neutralisation curve also eliminates the risk of over-acidification of the wastewater, so it can be used upstream of a biological treatment process."

What's more, SOLVOCARB® is also ideally-suited for the remineralisation of water following desalination techniques, for example reverse osmosis, to remove various impurities from the water. Following this process, the water still remains unsuitable for human consumption. In order to make the water potable, the pH, hardness and alkalinity are adjusted by the addition of lime and CO₂.

Jones highlights the fact that Afrox currently supplies SOLVOCARB® to a colliery in Mpumalanga, where permeate water produced from an acid mine drainage reverse osmosis plant is remineralised and made fit for domestic consumption.

CO₂ is stored in pressure vessels as a liquid and is converted to a gas at ambient temperatures before use. CO₂ is a highly soluble gas until dissolved readily in water, making it an ideal pH change agent. Due to its non-corrosiveness it eliminates the requirements for eyewash stations and safety showers that are mandatory with strong mineral acids.



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Looking Forward

VEGA

SA's future water crisis linked to current energy crisis

Within 35 years, South Africa will be short of fresh water which will be linked to the energy crisis. The preferred way to address this is through desalination. But unless the energy crisis is addressed, SA is destined for long-term power and water shortages primarily because power will be needed to produce clean water.

Trevor Blench, chairman of Steenkampskraal Thorium Limited (STL), said the solution lies in developing small thorium-based nuclear power stations, which are far safer than uranium-based power stations and more affordable. Thorium reactors use dry cooling or minimal water, either inland fresh water from rivers and dams or sea water along SA's coastline to create energy and desalinate water.

Blench said, while many parts of Africa are dry, the thorium reactor could desalinate sea-water for human consumption and produce water for irrigation. "Millions of people die every year in Africa from water-borne diseases. Our reactor could produce clean drinking water.

"Thorium represents an emerging and safe technology that is more efficient than uranium, produces significantly less hazardous waste and cannot easily be used for nuclear proliferation purposes," he said. "The solution to the energy and future water crisis is to develop small thorium-based nuclear power stations deployed at these strategic locations.

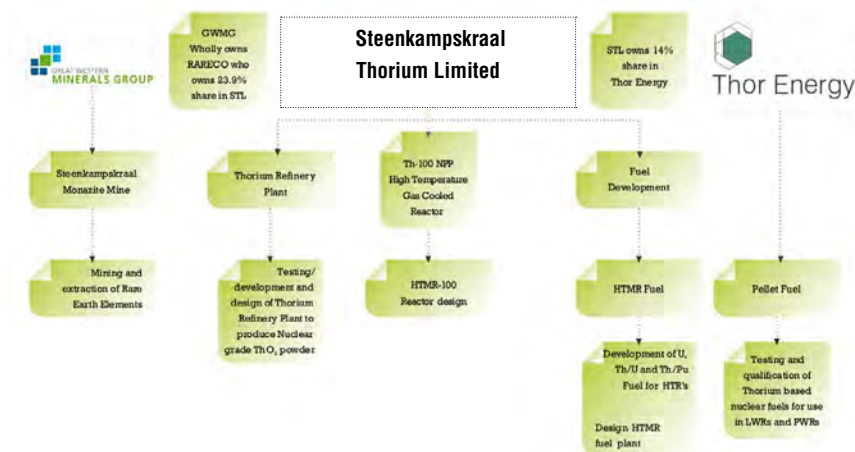
"SA has sufficient thorium reserves to supply all SA's energy needs for the next 100 years, which can also be used for desalination plants and for the safe production of electricity," he added.

Blench said that thorium fuel is being tested in Norway. STL owns the rights to the thorium of the Steenkampskraal mine in the Western Cape. He said that the Steenkampskraal mine has the highest known thorium and rare earth grades in the world.

"Thorium does not produce plutonium in its nuclear waste, neither does it produce trans-uranic actinides. It is therefore a much cleaner fuel than uranium. Our associate company in Norway, Thor Energy, has manufactured thorium fuel and is now qualifying this fuel for use in commercial reactors. We will be able to use thorium fuel in our reactor," he said.

Steenkampskraal was mined by Anglo American during the 1950s and 1960s for its thorium. About a dozen reactors were built in Germany, England and America at that time that used thorium and it is believed that most of that thorium came from this mine.

"We are designing a nuclear reactor that



is appropriate for Africa. Typically, African countries have a total annual electricity production of between 1 000 and 5 000 MW per year. They do not have well-developed grids to distribute electricity and currently generate a lot of their electricity with diesel generators, at very high cost.

"These countries cannot afford to spend billions of dollars buying big expensive reactors, up to ten years building such a reactor or plug a 1 000 MW nuclear reactor into their tiny grids," he said.

Blench said the reactor being developed will be suitable for African and remote conditions. "The reactor will be small. It will have a rating of 100 MWth (35 MW electric) and will be the right size for many African countries such as Namibia, Botswana, Ghana, Kenya and many others. It will be suitable for distributed generation, so that countries that do not have good grids could build several of these small reactors in different parts of the country. It will produce electricity more cheaply than the diesel generators being used today.

"It will also be affordable for the small countries that make up most of Africa and it will cost a fraction of the cost of large nuclear Light Water Reactors (LWRs). It will be modular and quick to build," he said.

Blench believes that if Africa is going to embark on a nuclear future, it should leap-frog over the Generation 3 reactors and go straight to Generation 4 reactors. "The technology is available. It has been tried and tested over many years. Our reactor is a Gen 4 design. What does that mean? It means that our reactor is intrinsically safe and meltdown-proof.

"It cannot melt down under any circumstances. The world over it is agreed that safety is the most important consideration in the nuclear industry. High Temperature Gas-cooled Reactors (HTGRs) have been demonstrated on several occasions, under the supervision of the IAEA, to be intrinsically safe and meltdown-proof. Another big advantage is that they are multi-purpose and capable of co-generation.

"There are many problems in Africa. Three of the biggest problems are food, water and power. Our plant can produce hydrogen in the form of ammonia. This 'hydrogen' could be used to make fertilizers to improve agricultural yields.

"Most parts of Africa suffer from power shortages that retard their rates of economic growth and hold down their living standards. Our small plant could provide electricity for remote towns and villages all over the continent," he concluded.

For more information contact Trevor Blench on tel: +27 12 658 5254, email: trevor.blench@thorium100.com or go to www.thorium100.com.



The profitable business of **climate change adaptation**

by Gavin Chait

“In marketing terms the end of the world will be very big,” says Ben Elton in his novel, ‘This Other Eden’. “Anyone trying to save it should remember that.” And – meeting all our end-of-world fantasies – is climate change.

Hotter summers, colder winters, drier, wetter, more storms, more hurricanes. Given how much people love dystopic movies, I continue to be surprised at the ongoing opposition to accepting the science. Whether we choose to deal with it or not, it is coming. And not everyone is sitting around waiting for it to happen.

As an impoverished student in the mid-1990s, I spent an entirely dull few weeks carefully slicing the radicle (tiny initial root) from dried peas. The University of Cape Town Microbiology Department was researching drought-resistant crops and was looking to extract the genes which make this possible in peas and transfer them to other food staples.

Climate change wasn't front-of-mind back then, but drought has always been with us. The looming climate crisis has simply made those weather cycles more extreme. Even as some areas have to cope with less water than ever, others are coping with regular flooding, cyclones, or searing summers and frigid winters.

In November 2012, Hurricane Sandy struck New York City. Over \$19 billion of property and commercial damage resulted, 250 000 vehicles were destroyed, and 53 people killed. Events like this will happen more often and will cause more damage.

Whether people, or the governments who represent them,



are prepared to accept the reality of climate change is immaterial. Businesses selling things, or protecting their existing markets, have to accept the impact on their companies. Insurers, dealing as they do with the future, have been amongst the earliest of adopters of climate change adaptation models, but companies across the world are developing new products, or adapting old ones, to counter the climate threat.

Take the simple problem of water-use. A WWF/SABMiller report declares that anywhere between 60 to 180 litres of water are used throughout the process of turning seed into one litre of beer. The average brewery uses five to six litres of water to produce a litre of beer. A world with less water will have to put the price up and, for many of us that implies that basic goods become unaffordable. Or, at worst, entirely unavailable.

SABMiller aims to reduce water consumption from 4,2 litres to 3,5 litres this year. But that is still small beer in comparison to the amount of water lost at the agricultural level. And farmers are having to figure out how to do more with less.

MillerCoors, a US subsidiary of SABMiller, has partnered with The Nature Conservancy on a demonstrator project in Idaho. Working closely with barley farmers, they have planted shade trees along rivers that irrigate the farms, to reduce temperatures and prevent evaporation. Vegetation has been



planted along river banks to stabilise the soil and prevent run-off of pesticides and pollutants. A water pump now irrigates closer to the ground and at lower pressure. The result is a saving of over 1 700 cubic metres of water annually.

Coca Cola and Pepsi are both working to reduce their water use in beverage manufacturing. By comparison, Coca Cola uses only 1,3 litres of water per litre of beverage, but their volumes are significant. They are promising to reduce that to 1,2 litres per litre.

Agriculture, though, is where water savings really need to be made. Research and product development has focused on two dimensions: more focused water use and efficiency in its management and distribution; and in genetically modifying crops to require less water in the first place.

John Deere has a range of precision irrigation systems. These, also known as drip irrigation, ensure that water is not randomly sprayed but delivered directly to plant roots. This minimises evaporation and over-watering, the two main culprits in inefficiency. Drip irrigation is mainly used by large-scale farmers because of the need for electronic control systems, pumps, valves and the various accoutrements of a processing plant. John Deere acquired Roberts Irrigation, which focuses on much smaller scale agriculture, including greenhouses, and at much lower cost.

Another area of high water use is in human waste disposal. Toilets themselves can use up to 15 litres of water with every flush, and processing of the sewage uses considerably more. GE is presently developing large mobile water-treatment plants for use in the Middle East which can return wastewater for human consumption or, in the most arid regions, desalination versions can produce large quantities of fresh water from the ocean.

The Bill and Melinda Gates Foundation “Reinvent the toilet challenge” is a project aimed at developing new treatment processes and more efficient ‘loos’. A recent demonstration of the system even used the biomass recovered from the process to power the treatment plant.

Efficiency, in other words, doesn’t just cater to environmental concerns, it is also very good for business effectiveness and profitability.

Genetic modification is also not only about staple crops. Ribena, a popular British drink made from blackcurrants, is threatened by the mild winters and warm summers in the UK. Blackcurrants have been grown in the UK since the 1800s, but, in some areas of the country such as Kent and Somerset, two varieties of blackcurrants – Baldwin and Ben Lomond – are suffering from increasingly poor yields.

GSK is working with The Scottish Crop Research Institute’s

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Blackcurrant Breeding Programme, and Ribena, to develop new strains of blackcurrant. They say that, "The aim is to produce a range of cultivars with superior fruit quality, pest and disease resistance and environmental adaptability in a changing climate. Two new varieties, Ben Vane and Ben Kilbreck, were successfully grown on a farm in Gloucestershire in 2008 and are now being grown commercially. Part of the success of this project was due to a good relationship between the partners and the UK farming community, which helped enable the trial and uptake of this new species."

Unfortunately, politics intrudes when it comes to GM foods. Africa, which is likely to bear the brunt of climate change, has also been subjected to sustained misinformation by environmental lobby groups. Already, Uganda's banana industry is being devastated by bacterial wilt. Elsewhere in the region, cassava – a fundamental food staple for millions – is being destroyed by two different viruses. In both cases there are GM versions which can be planted now that solve this problem. However, national anti-biotech legislation is in place to prevent GM agriculture.

The gradual changing conditions are aiding the spread of the viruses that cause these agricultural epidemics. Aid agencies are focused on teaching farmers how to clean their equipment or purify their seed-stock in order to stop transmission. Anathema is the discussion of the successful use of GM alternatives.

Disaster is concentrating minds. Kenya is finally bringing their biotech legislation up for review, but the expectation is that – without legislative change – the region will be unable to farm either bananas or cassava within the next 30 years. There is much to gain from improving our existing processes which – even without the incentive of climate change adaptation – would be useful for company effectiveness.

The danger is not just to food security. We also have to cope with increasingly violent and destructive weather extremes. Larger ocean storms are speedily eroding coastal areas and advancing on both commercial and residential property. Stabilising our shoreline to cope with wave-activity is also needed. Improved weather prediction can reduce loss of life.

BASF has developed a special elastomer polyurethane coating for gravel (Elastocoast) which is then used to create coastal revetments. These act to break and absorb wave action. The porous gravel absorbs the water and permits it to drain safely. With sea levels projected to rise by 50 cm over this century, numerous retaining walls, coastal defences and dikes will need to be raised. As an engineering exercise, it will be vast and expensive. BASF's product is said to be both renewable and low-cost.

Cotton, a highly water-intensive crop, could be displaced by new processes for extracting fibres from other bast fibres, like flax and hemp. And so it goes, with companies developing enhancements or alternatives to products at risk to climate damage. Consultants and companies specialising in supporting climate adaptation are already hard at work. It's already a multi-billion dollar industry active globally.

"Companies with expertise in water security are on the front lines of addressing changing climate adaptation," says Environmental Business Initiative President, Grant Ferrier. "Several leading consultancies have cut their teeth in Australia and other countries where governments have been forced to come to terms with chronic water scarcity. And now they're bringing that expertise to Texas and parts of the United States hit hard by drought and extreme heat."

Legislation that acknowledges climate change would still be useful. Like countries facing eminent famine and still refusing to recognise that GM crops are a safe and already-existing solution, governments similarly need to recognise that climate change has consequences whether you believe in it or not.

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Sales Success on LinkedIn - Nevil Tynemouth - Online

Date: 26 or 27 May 2015

Location: Online

Format: A one-hour online session: 40 minutes' presentation + 20 minutes' Q&A. Duration (for CPD recording purposes): up to one hour. If you are recording mandatory CPD you should refer to your own regulator's requirements as recognition of CPD hours may vary. Visit www.icheme.org/cpd for more information.

Charge: Free

Description: Consultants in organisations or working independently need to present and connect to other providers, suppliers and potential clients. In a survey of Consultancy Special Interest Group members, the membership said that social media was a top concern and wanted to know more about it. LinkedIn has become an important tool that enables easy connections and provides a platform for consultants to create more business both directly and indirectly. The Consultancy Special Interest Group is pleased to bring another top class speaker to give you valuable skills and knowledge for your career or business. The webinar is free of charge and open to all.

Event Type: Webinar

Venue: Online via GoToWebinar

Organiser: Consultancy Special Interest Group Contact

Email: specialinterestgroups@icheme.org

This online presentation, organised by the Consultancy Special Interest Group, will be delivered on two dates – 26 and 27 May.

Layer of Protection Analysis (LOPA) - October

Date From: 19 October 2015

Date To: 20 October 2015

Location: South Africa

Description: Covers the basic methodology of LOPA and the detailed stages of its application. Participants are shown how to identify significant scenarios, estimate frequencies for the worst-case events and how to assign risk categories.

Event Type: IChemE Course

Venue: Boksburg, South Africa

Organiser: IChemE

Contact Name: Rod Prior

Contact Phone: +27 (0)82 554 0010

Contact Email: r.prior@mweb.co.za

Fees: R5 500

<http://www.icheme.org/lopasa>



Rod Prior became South Africa's first IChemE Professional Process Safety Engineer in 2014.

Welcome to our new consulting editor

As Editor of 'Chemical Technology', I would like to extend a warm welcome to our new Consulting Editor, Carl Schonborn. Carl is a Chemical Engineer registered with ECSA as a Professional Engineer and a Member of SAIChE. He has over 30 years of extensive experience in the process design, installation and maintenance of refinery and petrochemical units, including project management, project engineering management, HAZOP facilitation and proposal management.

He has been involved in the conceptual and detail design of units in a number of industries including oil refineries, gas transmission facilities, tank terminals, grain handling and processing facilities, corn starch and syrup production units and the recycling of waste material.

He graduated from the University of the Wit-

watersrand with a BSc in Chemical Engineering and worked in the USA for the MW Kellogg Company on the design and optimisation of fluid catalytic cracker catalyst regenerators and petrochemical vessels.

On his return to South Africa, he worked for a number of private, local and international engineering contracting companies.

In his position as Consulting Editor of 'Chemical Technology' Carl hopes to assist the editorial team to publish articles and material which will be of interest to the local engineering community of southern Africa and in some way to instill a vision of what is possible in this great country of ours, South Africa.

I am sure that Carl's input, based on his experience in the field and his depth of knowledge of the subject, will have the effect of making 'Chemical Technology' a topical, relevant maga-



zine that will be 'the one' to go to for all the latest news and views.

So, welcome on board Carl and thanks for your positive contribution.

Evolution of Acid Mine Drainage formation in sulphidic mine tailings

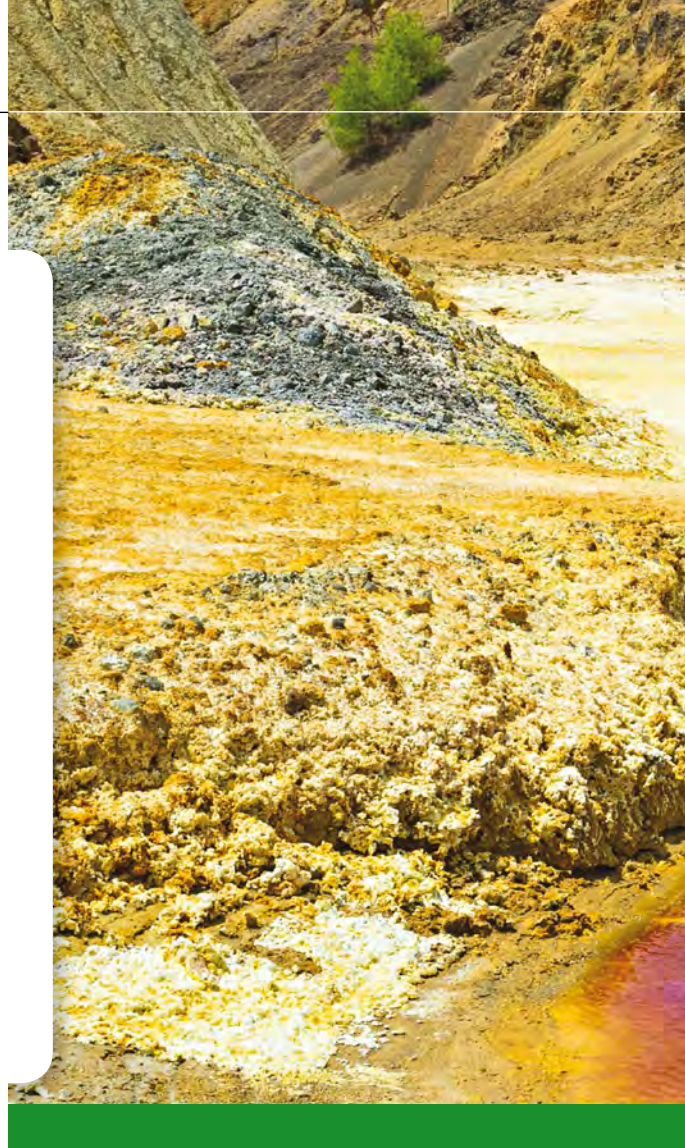
by Bernhard Dold, SUMIRCO (Sustainable Mining Research & Consult EIRL),
San Pedro de la Paz, Chile

Sulphidic mine tailings are among the largest mining wastes on Earth and are prone to produce acid mine drainage (AMD). The formation of AMD is a sequence of complex biogeochemical and mineral dissolution processes which can be classified in three steps from the operational phase of a tailings impoundment until the final appearance of AMD after operations ceased. This review summarises the work of 20 years of research on AMD's evolution and the controlling parameters of AMD formation in this type of mine waste.

Mine tailings are among the largest mining wastes on Earth and can reach surface areas of up to 52 km² [1] and be several hundred metres high. As this waste type results mainly from the flotation process of sulphide mineral ores they are very likely to produce acid mine drainage (AMD), the main environmental problem of contemporary mining activity. The on-land deposition has many environmental, socio-economic, and geotechnical stability problems, which can make them a limiting factor to production in the mining industry.

Tailings require large land areas and they have a great potential to produce ground and surface water contamination due to mineral dissolution in the operative and post-operative stage. Leaching from tailings results in an increase of oxyanions in solution (eg, sulphate, arsenate, molybdate) during operation, and AMD formation after operation. Additionally it also represents a threat downstream in case of catastrophic dam failures, as has happened in the past [2]. The public becomes concerned and the mining operations have to compete with alternative land uses like agriculture, fisheries, or tourism. As a result, the mining industry is re-evaluating the option of submarine tailings disposal (STD), a heavily disputed practice used in some locations over the last few decades primarily resulting in negative impacts on the environment (reviewed in an other paper of this special issue on submarine tailings disposal (STD) [3]).

The review starts with an introduction into the biogeochemical processes occurring during sulphide oxidation and then focuses on the very beginning of the process



in the transport channels of the tailings onto the tailings impoundments and the processes occurring in active operations. Then follows the evolution of AMD formation after the operation of the tailings impoundment has ceased, in relation to time, climate, deposition technique and flotation and finally ore deposit type will be analysed. The biogeochemical processes involved are highlighted in multi-extreme environments. At the end of this review, problems of management, remediation, and prevention options are discussed in order to increase the sustainability of mining operations.

For this purpose, we use mainly studies from porphyry copper ore deposits as examples, but this knowledge on the mineralogy and the resulting geochemistry can be extended with due caution to other sulphide ore deposits.

Sulphide oxidation

For the proper understanding of the formation of acid mine drainage, the biogeochemical interactions and the sequences in these processes have to be understood. This chapter is taken from Dold [4] for the convenience of the reader and more details on this issue can be found in this open access book chapter free of charge.

The problem of sulphide oxidation and the associated generation of acid mine drainage (AMD), or more generally acid rock drainage (ARD), as well as the dissolution and precipitation processes of metals and minerals, has been a major focus of investigation over the last 50 years [5,6,7,8,9]. The primary mineralogical composition has a strong influence on the oxidation processes. This has been

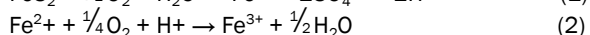
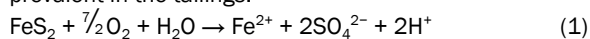


well illustrated [10,11,12], showing that reaction rates display significant differences depending on which sulphides are being oxidized by Fe(III) and the potential Fe(III) hydroxide coating. Kinetic-type weathering experiments indicate the importance of trace element composition in the stability of individual sulphides. Where different sulphides are in contact with each other, electrochemical processes are likely to occur and influence the reactivity of sulphides [13].

Most mines are surrounded by piles, dumps, or impoundments containing pulverized material or waste from the beneficiation process (Figure 1A), which are known as tailings, waste rock dumps, stockpiles, or leach dumps or pads. Waste rock dumps generally contain material with low ore grade, which is mined but not milled (Run of Mine; ROM). These materials can still contain large concentrations of sulphide minerals, which may undergo oxidation, producing a major source of metal and acid contamination [14]. In the following section the focus is on the acid producing sulphide minerals, mainly using pyrite as an example.

The most common sulphide mineral is pyrite (FeS_2). Oxidation of pyrite takes place in several steps including the formation of the meta-stable secondary products ferrihydrite ($5\text{Fe}_2\text{O}_3 \cdot 9\text{H}_2\text{O}$), schwertmannite (between $\text{Fe}_8\text{O}_8(\text{OH})_6\text{SO}_4$ and $\text{Fe}_{16}\text{O}_{16}(\text{OH})_{10}(\text{SO}_4)_3$), and goethite ($\text{FeO}(\text{OH})$), as well the more stable secondary jarosite ($\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6$), and hematite (Fe_2O_3) depending on the geochemical conditions [6,9,11,15,16,17,18]. Oxidation of pyrite may be considered to take place in three major steps: (1) oxidation of sulphur (Equation (1)); (2) oxidation of fer-

rous iron (Equation (2)); and (3) hydrolysis and precipitation of ferric complexes and minerals (Equation (4)). The kinetics of each reaction is different and depends on the conditions prevalent in the tailings:



Reaction rates are strongly increased by microbial activity (eg. *Acidithiobacillus* spp. or *Leptospirillum* spp.):



Equation (1) describes the initial step of pyrite oxidation in the presence of atmospheric oxygen. The oxidation of ferrous iron to ferric iron, is strongly accelerated at low pH conditions by microbiological activity (Equation (2), producing ferric iron as the primary oxidant of pyrite (Equation (3)) [7,19,20]. Under abiotic conditions the rate of oxidation of pyrite by ferric iron is controlled by the rate of oxidation of ferrous iron, which decreases rapidly with decreasing pH. Below about pH 3 the oxidation of pyrite by ferric iron is about ten to a hundred times faster than by oxygen [21].

It has been known for more than 50 years that microorganisms like *Acidithiobacillus ferrooxidans* or *Leptospirillum ferrooxidans* obtain energy by oxidizing Fe^{2+} to Fe^{3+} from sulphides by catalyzing this reaction [22] and this may increase the rate of Reaction (2) up to the factor of about 100 over abiotic oxidation [23]. More recent results show that a complex microbial community is responsible for sulphide oxidation [19,24,25,26,27]. Nordstrom and Southam [28] stated that the initiating step of pyrite oxidation does not require an elaborated sequence of different geochemical re-

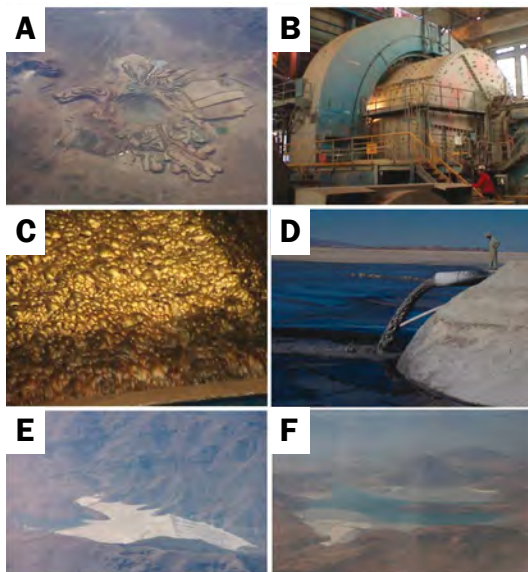


Figure 1. (A) Open pit mine surrounded by waste dumps and stock-piles. (B) Semi-Autogenous Grinding (SAG) mill. (C) Froth flotation of chalcopyrite concentrate. (D) Deposition point of a tailings impoundment. (E) Aerial photograph of a valley dam tailings impoundment. Note the slight saturation of the tailings and the seepage in the dam (dark humid spots in the dam). And (F) aerial view of a big tailings impoundment with near complete water saturation.

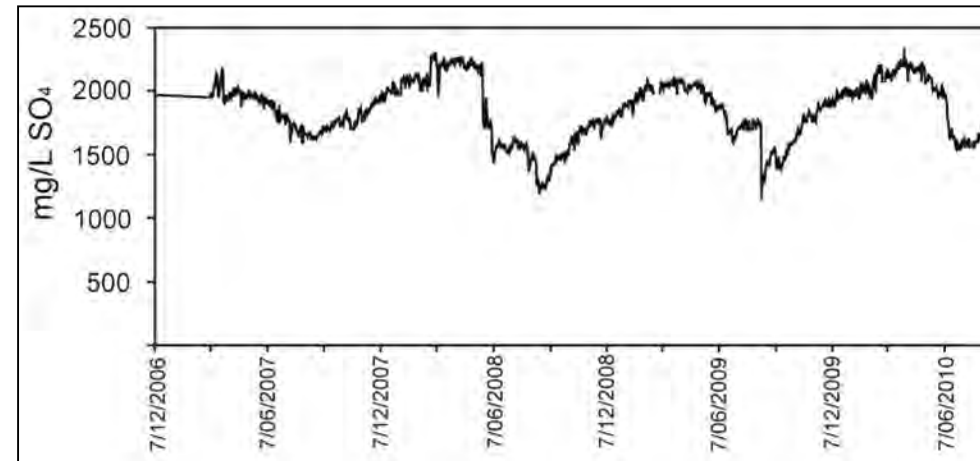


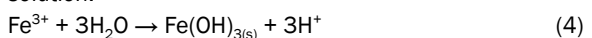
Figure 2. Example of the evolution of dissolved sulphate concentrations (in mg/L) in the decantation pond of an active tailings impoundment during a five year period. A clear seasonal trend is observed, peaking end of summer due to evaporation effects.

actions that dominate at different pH ranges. *Acidithiobacillus* spp. forms nano-environments, which grow on sulphide mineral surfaces [29]. These nano-environments can develop thin

layers of acidic water that do not affect the bulk pH of the water chemistry. With progressive oxidation, the nano-environments may change to microenvironments [30]. Evidence of acidic microenvironments in the presence of near neutral pH for the bulk water can be inferred from the presence of jarosite (this mineral forms at pH around 2) in certain soil horizons where the current water pH is neutral [31]. Barker et al [32] observed microbial colonization of biotite and measured pH in microenvironments in the surroundings of living microcolonies. The solution pH decreased from near neutral at the mineral surface to pH 3–4 around micro-colonies living within confined spaces at interior colonized cleavage planes.

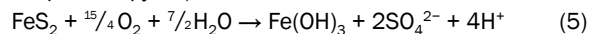
When mine water, rich in ferrous and ferric iron, reaches the surface it will fully oxidise and hydrolyse, resulting in the precipitation of ferrihydrite (Fh), schwertmannite (Sh), goethite (Gt), or jarosite (Jt) depending on the pH-Eh conditions, and availability of key elements such as potassium and sulphate (Figure 2). These secondary minerals like jarosite, schwertmannite and ferrihydrite are meta-stable and can transform into goethite [17].

The hydrolysis and precipitation of iron hydroxides (and to a lesser degree, jarosite) will produce most of the acid in this process. If the pH is less than about 2, ferric hydrolysis products like $\text{Fe}(\text{OH})_3$ are not stable and Fe^{3+} remains in solution:



Note that the net reaction of complete oxidation of pyrite, hydrolysis of Fe^{3+} and precipitation of iron hydroxide (sum of Reactions (1), (2) and (4) produces four moles of H^+ per mole of pyrite (in case of $\text{Fe}(\text{OH})_3$ formation, see Reaction (5), i.e., pyrite oxidation is the most efficient producer of acid among the common sulphide minerals (net Reaction (5)). Nevertheless, it is important to be aware that the hydrolysis

of $\text{Fe}(\text{OH})_3$ is the main acid producer ($\frac{3}{4}$ of the moles of H^+ per mol pyrite).

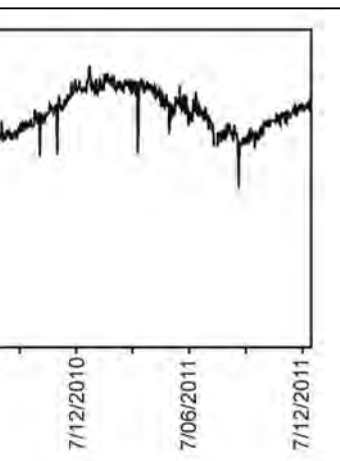


The process of pyrite oxidation relates to all sulphide minerals once exposed to oxidizing conditions (eg, chalcopyrite, bornite, molybdenite, arsenopyrite, enargite, galena, and sphalerite among others). In this process different amounts of protons are released [4] and the metals and other harmful elements or compounds are released to the environment.

From the flotation process to the active tailings impoundment

The goal of the flotation process is to separate the economically valuable target minerals from the gangue minerals, which have no economic value at the time of exploitation [33]. In order to be able to do this, the rocks extracted from the mine (underground or open pit) as coarse ROM granulometry (including blocks of 1 m diameter down to rock powder), have to be broken, ground and milled (Figure 1B) to a very fine grain size, in order to be able to separate on the addition of chemical reagents, selectively the target minerals (ie, to make it hydrophobic, which then enables it to attach to introduced air bubbles and so float towards the surface of the flotation cell (Figure 1C), where it can be harvested) [34,35]. Non-economic sulphide minerals, like pyrite can be suppressed from flotation as for example by pH adjustment (alkaline circuit), and end up in the waste materials, which are called tailings (Figure 1D).

As the flotation process has a recovery of 80 %–90 %, between 10 % and 20 % of the target mineral ends up in the tailings together with the non-economic sulphides like pyrite or other accessory sulphides, which can contain other environmentally harmful elements. These tailings are then sent in suspension via tubes, channels or directly in riverbeds towards their final disposal sites (Figure 1D), ie, a river, lake(s), or the sea, but mainly in mines today on-land in constructed, tailings impoundments or dams (Figure 1E,F). Depending on the geochemical conditions of this final disposal site, the mineral assemblage in the tailings can undergo geochemical oxidative processes, which can lead to the release of metals, toxic compounds, and acid. The geochemical and mineralogical effects of disposal of mine tailings in reduc-



ing environments is reviewed in another paper of this special issue concerning submarine tailings disposal (STD) [3]. The present review focuses on the processes resulting from the exposition of sulphidic mine tailings to oxidation in on-land tailings impoundments.

The whole flotation process is performed using a mineral suspension with a solids-water ratio of about 40 %:60 %. Thus, the flotation is a highly water-consuming process, and

therefore water is the limiting factor for mine development in many arid to semi-arid regions (eg, Northern Chile and Southern Peru). Some mining operations have opted to use marine water for the flotation process [36,37]. Water recycling from the decantation pond of the tailings impoundment is also a common practice to recovery industrial water. New techniques like paste tailings and dry staking recover water before final deposition and increase geotechnical safety of the tailings deposit [38,39]. However, it should be noted that sulphide oxidation is enhanced by these new techniques, as the tailings are never completely water saturated, but humid, and oxygen can more easily reach the sulphides, compared to the traditional water-saturated tailings impoundments.

In the flotation process, tailings come in to contact with water and oxygen for the first time, leading to Reaction (1). However, at this stage the oxygen supply is limited, as only dissolved oxygen is available for the sulphide oxidation in the flotation process. As most flotation processes are maintained artificially at alkaline pH conditions in order to suppress the flotation of pyrite, sulphide oxidation during the flotation does not result in extensive acid generation. However, isotopic studies ($\delta^{34}\text{S}$, $\delta^{18}\text{O}$) of dissolved sulphate suggest along a 87 km long tailings channel that sulphide oxidation starts in the flotation process and during transport towards the final disposal site [40]. Additionally, if the ore has oxyanions associated with iron oxide minerals, for example when ore is slightly pre-oxidized by supergene processes in the upper part of the ore deposit, then, due to the alkaline flotation circuit, As and Mo can be desorbed during flotation and possible make it necessary to implement an

abatement plant for these elements, as is the case for Mo in the El Teniente mine, Chile.

When the tailings reach the active tailings impoundment, they should then in a strict sense be maintained water saturated in order to minimize oxidation of the sulphide minerals (water contains a maximum of approximately 10 mg/L dissolved oxygen). This is not always the case or possible, for example due to high evaporation rates in dry climates, so that often parts of the tailings are exposed during summer time to a thin unsaturated zone to oxidation even in active tailings impoundments (Figure 1E). At this stage, the 21 % of atmospheric oxygen will start to oxidize the sulphide mineral assemblage present in the tailings. This goes hand-in-hand with the increase of pore water concentration in metals and oxyanions like (Na, K, Cl, SO_4 , Mg, Cu, Mo) towards the surface due to capillary transport, and the formation of efflorescent salts on the surface, like halite, gypsum, and Na-K-Ca-Mg sulphates like mirabilite $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ and syngenite $\text{K}_2\text{Ca}(\text{SO}_4)_2 \cdot 4\text{H}_2\text{O}$ [1,40]. Due to neutral to alkaline pH at this stage, only major cations together with sulphate and chloride are mobile and the resulting efflorescent salts are mainly white in colour.

Another commonly observed geochemical process occurring in active tailings of porphyry copper deposits is a strong increase in sulphate concentrations, which typically range between 1 500 and 2 000 mg/L, with an annual trend to increase towards the end of summer (Figure 2) and sometimes a general increase with time can also be observed. The sulphate concentrations are controlled by the solubility of gypsum [40,41], often present in an ore deposit (gypsum or anhydrite), and the increase by the release of sulphate due to weathering processes associated with sulphide oxidation. Neutralization reactions, eg, silicate weathering, liberates major cations into solution, which then form sulphate complexes, so that higher concentrations of sulphate can stay in solution, than can be explained by the solubility of gypsum alone.

In some tailings impoundments the formation of AMD can be visualized during the operational phase in the dam area [42,43]. This is mainly the case when the dam is made of the coarser fraction of the tailings (eg, hydro-cyclone separation). This results in a higher content of sulphide minerals in the dam material, which has also a coarser grain size (sandy material). Additionally, the dam must be maintained in an unsaturated condition for stability reasons, so that this area is an excellent environment for

Summarizing, active tailings impoundments might have the following environmental problems:

1. Increased sulphate concentrations (between 1500 and 2000 mg/L), if gypsum and/or anhydrite are present in the ore mineralogy (eg, porphyry copers). The sulphate concentrations are controlled by the gypsum equilibrium. The sulphate concentrations can additionally increase with time in the tailings impoundment, depending on increasing input of major cations from weathering processes.
2. If oxyanions (eg, arsenate, molybdate) are associated with Fe(III) hydroxides from the primary ore mineralogy, they will potentially be released in the alkaline flotation process.
3. During the flotation process and tailings transport, sulphide oxidation can begin, but will not be able to strongly influence the geochemical regime (ie, the pH will not drop dramatically). In the active tailings impoundment, when a thin, unsaturated zone develops in the dry season, then sulphide oxidation can lower pH conditions and increase the metal release in the uppermost part of the tailings.
4. In situations where tailings dams are constructed by coarse tailings material, sulphide oxidation might lead to the release of AMD from the unsaturated dam area. This might be visible by the precipitation of schwertmannite and/or ferrihydrite [42,43].
5. The precipitation of these Fe(III) hydroxides in the pore space of the tailings dam might change the permeability and so produce stability problems for the tailings dam.

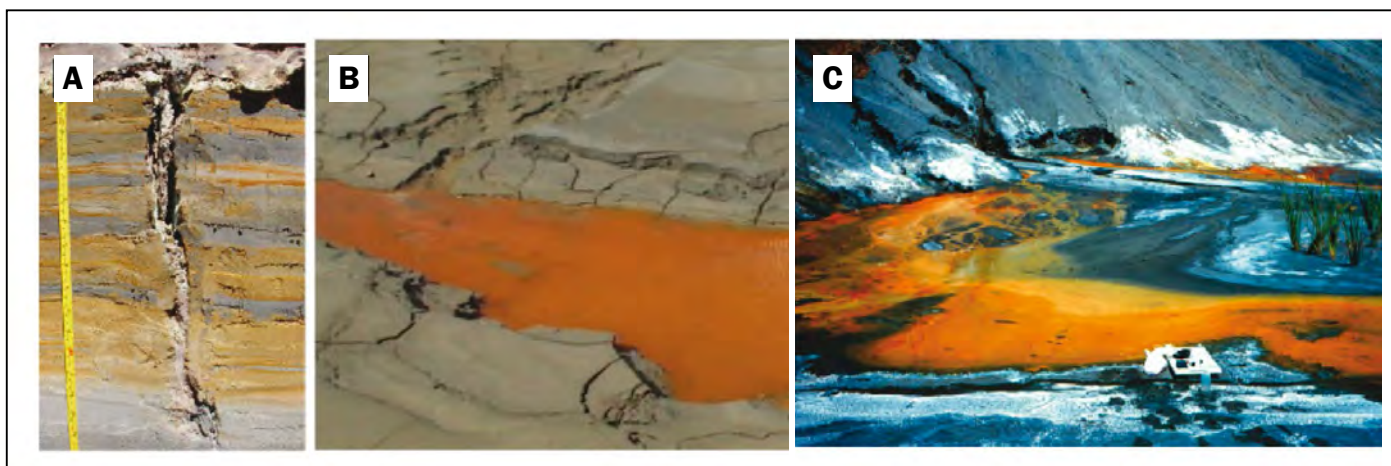


Figure 3. (A) Oxidation zone in the Talabre tailings impoundment after five years of oxidation (pH 3,9). Clearly visible the precipitation of Fe(III) hydroxides and the oxidation front [1]. (B) Precipitation of ferrihydrite in an active tailings impoundment due to the exposure of Fe(II)-rich waters to the atmosphere (Ocroyoc, Cerro de Pasco, Peru) [14]. And (C) outcrop of AMD (pH 3,15) at the foot of an active tailings dam with the precipitation of schwertmannite (Ojancos, Hochschild, Chile) [42].

sulphide oxidation, which is visible by the precipitation of schwertmannite from the effluents at the foot of the dam [42,43]. The presence of schwertmannite directly at the outcrop of the tailings dam, suggests that acidic (pH 2–4) and ferric iron rich solutions are leaching from the tailings. If a ferrous iron rich neutral plume flows out from the dam, then iron oxidation will occur followed by hydrolysis and subsequent ferrihydrite precipitation [43]. If the ferrous iron rich plume is acidic, then temperature, pH, and microbiological activity will determine how fast the ferrous iron will be oxidized in the drainage stream [44,45] in order to be able to subsequently hydrolyze and precipitate as lepidocrocite, schwertmannite, jarosite or ferrihydrite, depending on the final geochemical conditions.

In general, it can be pointed out, that if an active tailings impoundment shows signs of acidification in the decantation pond during operation or even of AMD formation, then severe management problems can be assumed.

Evolution of post-deposition geochemical processes in tailings impoundments

In order to study the evolution of sulphide oxidation in a natural environment after the operation has ceased, the Talabre tailings impoundment of the Chuquicamata porphyry copper mine was investigated [1]. Although the Talabre tailings impoundment is an active impoundment, its dimensions (52 km² surface area) and deposition technique allowed a study of tailings exposure at a well defined time frame under the hyper-arid conditions of the Atacama Desert. As the deposition point is periodically changed on the tailings surface of the impoundment and the tailings are disposed of into different basins, there was an exact register available of how long the tailings were exposed to the atmosphere, ie, weathering. This gave the possibility to select the samples sites from fresh tailings (actual discharge point at time of sampling) up to five years of exposure and track the mineralogical and geochemical changes over time. The mineralogy of the tailings is typical of porphyry copper systems, with pyrite as the major sulphide (1,75 wt %), followed by chalcopyrite and bornite. Minor sulphide fractions found in polished sections were enargite, covellite,

chalcocite and sphalerite. There were no carbonates present in the mineral assemblage and the gangue mineralogy was dominated by quartz, K-feldspar, plagioclase, biotite, chlorite, muscovite and gypsum. Primary anhydrite was not found due to hydration to gypsum during flotation. Apatite, rutile, magnetite, hematite, and goethite occurred in trace amounts [1].

The key parameters, pH and Eh, evolved from alkaline (fresh tailings pH 9,1) towards acidic and from reducing to oxidizing conditions. After three years of oxidation the pH was still in the circumneutral range (pH 6,4–7,5), while after four years a drop to acidic conditions was observed (pH 4,7) at the surface (0–4 cm), leading to a pH of 3,9 after five years with the development of a well defined 29 cm thick oxidation zone (Figure 3A).

Associated with this geochemical change, the main element groups in this system showed their characteristic behaviour and distribution. The major cations and anions showed an increasing trend of enrichment towards the tailings surface, due to capillary transport in the hyper arid climate [1,46,47,48], with the fast precipitation of halite, gypsum, and Na-K-Mg-Ca sulphates and chlorides at the surface (mainly white efflorescent salts). Heavy metal cations like Cu, Zn, and Ni were not mobile in the neutral to alkaline pH conditions in the first years due to their sorption behaviour to iron oxides. However, after five years of oxidation, the drop of the pH in the oxidation zone resulted in increasingly high concentrations of Cu (up to 170 mg/L) and Zn (150 mg/L) in the pore water near the surface of the tailings. This was visible by the precipitation of greenish eriochalcite (CuCl₂·2H₂O) on the tailings surface, as observed in other chloride-rich environments [47,48].

In contrast, arsenic and molybdenate, which are stable as oxyanions in solution, occurred in high concentrations in the pore water due to the alkaline conditions at the beginning of weathering. The origin of these elements is mainly due to high natural background concentrations of As in the area [49], desorption of oxyanions associated with Fe(III) hydroxides in the ore mineralogy, and increasing concentrations in the recycled industrial water due to evaporation. With decreasing pH by sulphide oxidation and hydrolysis of Fe(III) hydroxides in the oxidation zone, arsenate and

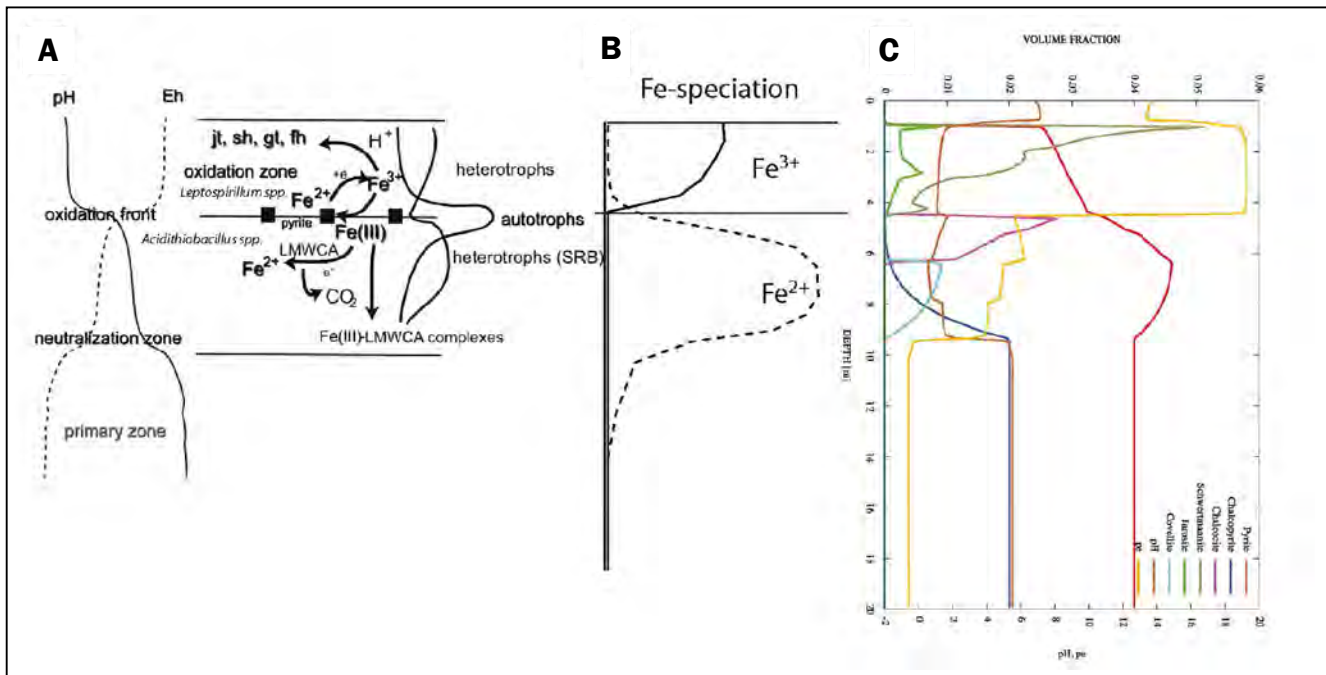


Figure 4. (A) Schematic model of biogeochemical iron cycling at the sulphide oxidation front (modified after Dold *et al* [55]). (B) Schematic iron speciation as a function of the tailings depth (modified after Dold *et al* [55]). And (C) volume fraction of the different primary and secondary sulphide and ferric iron oxide minerals as a function of tailings depth obtained by reactive transport modelling by Peter Lichtner with the code FLOTRAN [59] for 50 years of oxidation based on pore water composition in the Piuquenes tailings impoundment (with permission). The mineral distribution modelled is confirmed by the detected mineralogy in this tailings profile [46].

molybdenate decrease their concentrations in the pore water of the oxidation zone to below detection limits due to the well known adsorption to the neo-formed sorbents (Fe(III) hydroxides). This is confirmed by sequential extraction data, showing a strong increase of As (175 mg/kg) and Mo (155 mg/kg) associated with the Fe(III) hydroxide fraction in the upper oxidation zone after five years of oxidation. Stable isotope data also clearly demonstrated that sulphate had its origin at the beginning from gypsum dissolution, while in the acid oxidation zone a clear change towards the supply of sulphate by sulphide oxidation is observed [1].

These findings explain why standard kinetic cell tests for AMD prediction (ASTM D5744-96) [50] do not correctly predict the behaviour of porphyry copper material [51,52]. As seen in the case of Talabre, the material needs at least 3–4 years in order to reach acidic pH conditions, and this without any buffering from carbonates. Therefore, the time frame proposed in the standard method of 25 cycles (half year or up to one year depending on the length of each cycle), is far too short in order to reach, ie, predict, acidic conditions in the porphyry copper system. While there is some improvement, ie, increased oxidation kinetics with new modified cell tests [53,54], they still have to be run for at least 2–3 years, until acid conditions are reached (in case the acid base accounting indicates an excess of acid potential; the usual case for porphyry copper deposits [46]). This increases the costs and time scale for mine waste characterization, which is not very attractive for the mining industry.

In the study of the Talabre tailings impoundment, another important process for tailings management could be observed. As the tailings deposition point returns periodically to the same place of deposition, where the tailings were exposed to oxidation over several years with the subsequent

formation of the above described oxidation zone and formation of efflorescent salts on the surface, this re-deposition will have the following geochemical impact: As explained before, after 4–5 years a well defined acid oxidation zone has developed with the formation of secondary Fe(III) hydroxides (Figure 3A), which have the role of the sorbent for arsenic and molybdenum in these geochemical conditions. With the new deposition of fresh alkaline tailings in the same place where the acid oxidation zone formed in an unsaturated zone of the tailings stratigraphy, the system is changed to saturated, alkaline reducing conditions. This will first dissolve all efflorescent salts and liberate the associated elements into the aqueous phase, but also it will initiate the reductive dissolution of Fe(III) hydroxides from the oxidation zone, which will liberate the associated As (up to 23 mg/L) and Mo (up to 16 mg/L) to the groundwater of the tailings impoundment [1].

Biogeochemical iron cycling at the oxidation front: the first step in the formation of acid mine drainage (AMD)

Until now we have observed how the system evolves over time at the surface and its element-release sequence. In this section we will enter in more detail into the biogeochemical interactions occurring at the oxidation front and in the vertical stratigraphy, in oxidation zones that are well developed.

This is the case (for example), after 16 years of oxidation in the high mountain climate Piuquenes tailings impoundment, Chile [46,55,56,57,58]. Its oxidation zone reached pH 2.3–3 and nearly all sulphide minerals were oxidized ($E_h = 750$ mV), only some relicts of pyrite and chalcopyrite remained (Figure 4). The secondary mineral assemblage was controlled by schwertmannite, jarosite, gypsum, and

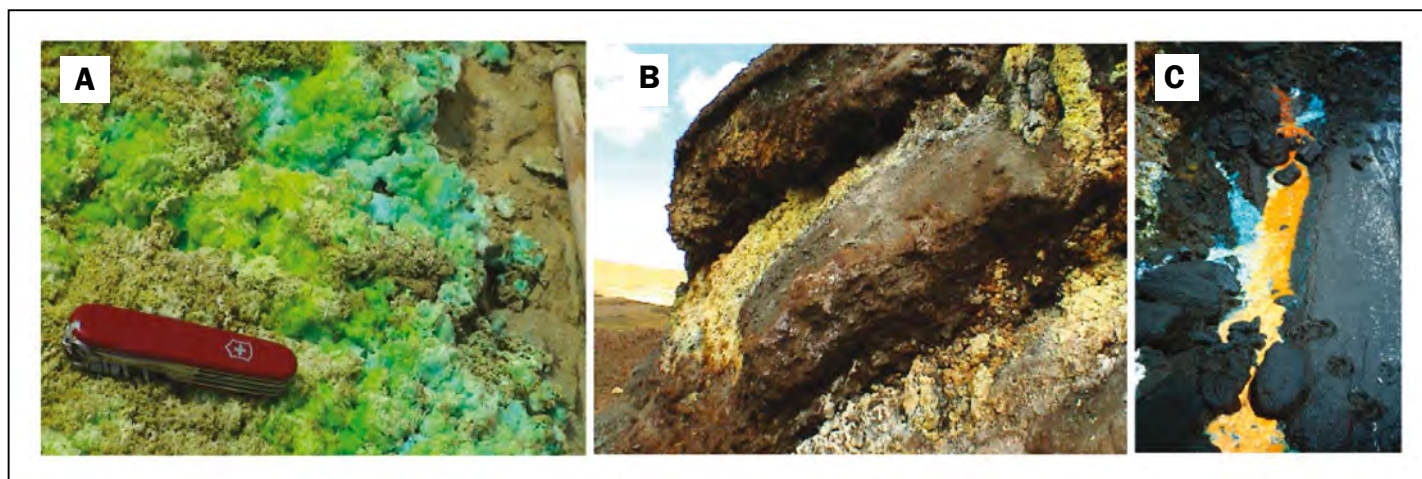


Figure 5. Acid flow precipitates: (A) Efflorescent salts surface of acid oxidation zone pH 2,5, Ite Bay, Peru. (B) Efflorescent salts at the Excelsior Waste rock dump, Cerro de Pasco, Peru. And (C) acid Effluent with chalcoalumite precipitation (light blue) at pH 4,9 and schwertmannite at pH 3.15 (orange-brown) at Ojancos, Copiapo, Chile.

a vermiculite-type mixed layer mineral resulting from the alteration of biotite in the oxidation zone [46]. Below the oxidation front, a change from acidic-oxidizing conditions towards more reducing (500 mV, which is controlled by the $\text{Fe}^{3+}/\text{Fe}^{2+}$ redox pair) and an increase to pH 4,5 (Gibbsite buffer) can be observed [55] (Figure 4B). Iron speciation in the pore water was dominated by ferric iron in the oxidation zone (up to 2 000 mg/L), while directly below the oxidation front a ferrous iron plume of up to 4 000 mg/L could be detected [55].

The above-mentioned increase of pH at the oxidation front should initiate the hydrolysis of the Fe^{3+} ions and the precipitation of Fe(III) hydroxides in this area of the profile. However, data from sequential extractions show the contrary, that at the oxidation front and below there were less secondary Fe(III) hydroxides precipitated than in the oxidation zone itself and the underlying primary zone [55]. This can be explained as follows (Figure 4A): At the oxidation front, main microbial activity was detected by Diaby *et al* [57], due to the fact that sulphides are still available as energy source (in the oxidation zone they are mainly consumed and only ferric iron is available). In this study, the authors also found that *Leptospirillum* spp. are dominating the system and that the bacterial population was about 100 times greater at the oxidation front than above or below this horizon. However, *Acidithiobacillus* spp. and *Acidiphilium* spp. were also detected and seemed to be mainly responsible for iron reduction in this system, as *Leptospirillum* spp. is only able to oxidize ferrous to ferric iron. The $\delta^{18}\text{O}$ values of dissolved sulphate suggest that from the top of the oxidation zone downwards to the oxidation front, a change from initially atmospheric oxygen towards oxygen from water can be observed. This indicates that at the oxidation front sulphide oxidation takes place by ferric iron, while towards the tailings surface more atmospheric oxygen is involved [56].

Sulphate reducing bacteria were also detected, and found to have their highest number below the oxidation front, so that some sulphate reduction can be expected. However, stable isotopic data suggest that due to the lack of increase of $\delta^{34}\text{S}$ shift towards heavier signature in this area of the profile, sulphate reduction is not occurring in

a significant amount in this system, possibly due to the limited availability of organic matter. In the oxidation zone, no organic molecules like low molecular weight carboxylic acids (LMWCA) could be detected, so that the only organic matter is possibly dead bacteria cells available for organic carbon cycling. In contrast, below the oxidation front a peak of LMWCA, like acetate, formate, and pyruvate could be detected. Associated with this LMWCA peak, which is interpreted to be a result of the microbial activity around the oxidation front, the ferrous iron plume and an increase in CO_2 in the pore gas correlates directly [55,60]. These data suggest that the microbial community, in this case mainly *Acidithiobacillus ferrooxidans* and/or *Acidiphilium* spp. [61] use the monodentate LMWCA like acetate and formate as electron donors and ferric iron as electron sink, resulting in the reduction to ferrous iron and the formation of CO_2 [55]. This reduction increases the mobility of iron, as now the ferrous iron can migrate in the circumneutral pH conditions of the underlying tailings stratigraphy until it outcrops at the foot of the dam, where it will auto-oxidize and hydrolyze to form ferrihydrite (outcrop pH still neutral).

Another process, which might enable the ferric iron to pass the geochemical barrier of the oxidation front, is via complexation by bidentate LMWCA like oxalate or pyruvate, which changes the solubility and therefore, these complexes might reach a lower tailings horizon, where then again the microbial community will reduce it to ferrous iron and CO_2 . Thus, these processes explain why at and below the oxidation front less secondary Fe(III) hydroxides precipitate and instead a ferrous iron plume is formed due to iron reduction processes. This plume can now migrate in the system until it encounters more oxidizing condition or higher pH conditions (eg, in contact with carbonate rich strata, which then promote the hydrolysis of ferrihydrite). This will be the first visible indication of AMD formation, although the main flow path in the tailings is still neutral (Figure 3B).

The change in redox at the oxidation front also triggers the replacement of chalcopyrite with covellite by copper, leached out from the overlying oxidation zone downwards (Figure 4B), due to general downwards-dominated movement of the released elements in the rainfall-dominated alpine climate of Piuquenes [46]. The thickness of this cop-

per enrichment is limited by a second pH increase towards pH around 5,5–6 (siderite buffer) at 3 m depth, as Cu is only mobile until pH 5 in freshwater and is therefore adsorbed at higher pH conditions [46]. As the oxidation front is defined by the drop of oxygen concentrations to zero in the pore gas of the tailings profile (70 cm depth), which correlates with a pH and redox switch, and the groundwater level was at 4 m depth, the copper enrichment zone is defined between oxidation front and siderite buffer (0,7–3 m depth) [55]. This means that the general belief that supergene enrichment is associated with the groundwater level is not necessarily correct. It is defined by the oxidation front and the pH gradient induced by the neutralization reactions of the gangue mineralogy, which controls the thickness of the mobility window of copper (pH <5 and Eh <500 mV), necessary for the enrichment process. This is the case in fresh water systems, but in high-chlorine system Cu can be mobile at neutral pH as Cu(II)Cl_2 or Cu(I)Cl_2^- complexes [47].

Consumption of the neutralization potential and final acid flow

As discussed above, the resulting ferrous iron plume is the first sign of AMD that might outcrop. However the production of protons still goes on at the oxidation front and in the oxidation zone. These protons interact with the gangue mineralogy and will be partly neutralized, liberating other elements into solution from the dissolution processes of carbonates and silicates. Therefore, depending on the composition of the mineral assemblage of the gangue mineralogy a specific neutralization sequence can be observed across the tailings stratigraphy, which is controlled by the different buffering minerals.

For example, in the Piuquenes tailings impoundment the carbonates present are dominated by siderite with traces of calcite. Thus, when the protons produced by sulphide oxidation migrate with the acid solution downwards, first calcite will buffer to around neutral pH until it is completely consumed or passivated by iron oxides. Then siderite will buffer the system to around pH 5,5, until it is consumed. Then the pH can drop further down to around pH 4,5, where the gibbsite buffer will maintain the pH until also this buffer is consumed. Finally, in the oxidation zone itself, the Fe(III) hydroxide assemblage will buffer the pH around the typical pH between 2 and 3 in this area. If it is close to pH 2 a dominance of jarosite can be expected, while if it is closer to pH 3 schwertmannite will control the system [4,46,55]. If there is still an excess of protons added to the system, in some cases even the jarosite buffer might be consumed and even negative pH can be reached as reported from Iron Mountain [62].

This sequence of pH values increases from 2–3, to 4,5, 5,5 and neutral correlates with a successive decrease in redox potential occurring in oxidised tailings, clearly defining the geochemical systems active in each zone, and controlling which elements can be mobilized downwards through the tailings stratigraphy.

Oxyanions like arsenate and molybdate are retained effectively by the Fe(III) hydroxides due to sorption at low pH conditions in the oxidation zone. Below, due to reduction of arsenate to arsenite or at very low pH condition arsenate

will be completely protonized and therefore the mobility might be increased for arsenic under these specific conditions [63].

Heavy metals occur mainly as divalent cations, stable in solution and mobile at low-pH conditions. With increasing pH, they become adsorbed and therefore immobile [4]. Additionally, as observed above in the case of copper, replacement processes and reduction processes can precipitate the metals as secondary sulphides or hydroxides in a deeper part of the stratigraphy [46]. As the system will increasingly acidify, these secondary sulphides will be re-dissolved and so the acid oxidation zone migrates further down, increasing the mobility of the heavy metals. When the protons produced in the oxidation zone exceed the neutralization capacity of the gangue mineralogy below in the tailings stratigraphy, the situation can be reached where the whole flow path is under acid conditions, so that the acid, heavy metal rich solution can outcrop at the foot of the tailings dam, or infiltrate into the groundwater. This will be visible with a broad range of bright colours of the precipitates forming at the outcrop, as secondary heavy metal sulphate minerals can have blue, yellow, green, or red colours, depending on their composition (Figure 5). Therefore, when you observe bright colours at the foot of your tailings dam, you can expect an advanced system with acid flow path, or you have an active tailings dam built using the coarse tailings fraction and you are observing the effect of the sulphide oxidation in the unsaturated dam.

Some common errors in AMD and mine waste management

AMD management → **Fe³⁺-Rich solutions**

In mines, where AMD occurs, the Fe^{3+} -rich solutions are sometimes pumped into the active mine tailings. This has to be avoided, as the input of ferric iron to sulphide rich material will efficiently oxidize the sulphides and produce 16 moles of protons per mole of pyrite oxidized (Equation (3)), with the result that the pH might drop quickly in the active tailings impoundment [14]. Therefore, mine management strategies need to prevent the contact of the Fe^{3+} -rich solution with any sulphide containing material.

Fe³⁺-rich sludge or mud from AMD neutralization or treatment plants

Lately, due to increased efforts in the mining industry not to dispose AMD to the environment, many mines have implemented AMD neutralisation or treatment plants. This process produces a certain volume of sludge or mud, which is mainly ferrihydrite, lepidocrocite, goethite [64], schwertmannite [65], depending on the process, with co-precipitated and/or adsorbed elements like arsenic, molybdenum or heavy metals. Thus, this sludge is now a hazardous waste material, which has to be managed properly. An often-used solution for its disposal and unfortunately performed in many mining operations is the deposition of iron oxide sludge in the active tailings impoundment.

The problem with this practice is highlighted here: The sludge of the treatment plant contains mainly Fe(III) hydroxides like ferrihydrite or schwertmannite, the two unstable Fe(III) hydroxides. If we dispose of this sludge together

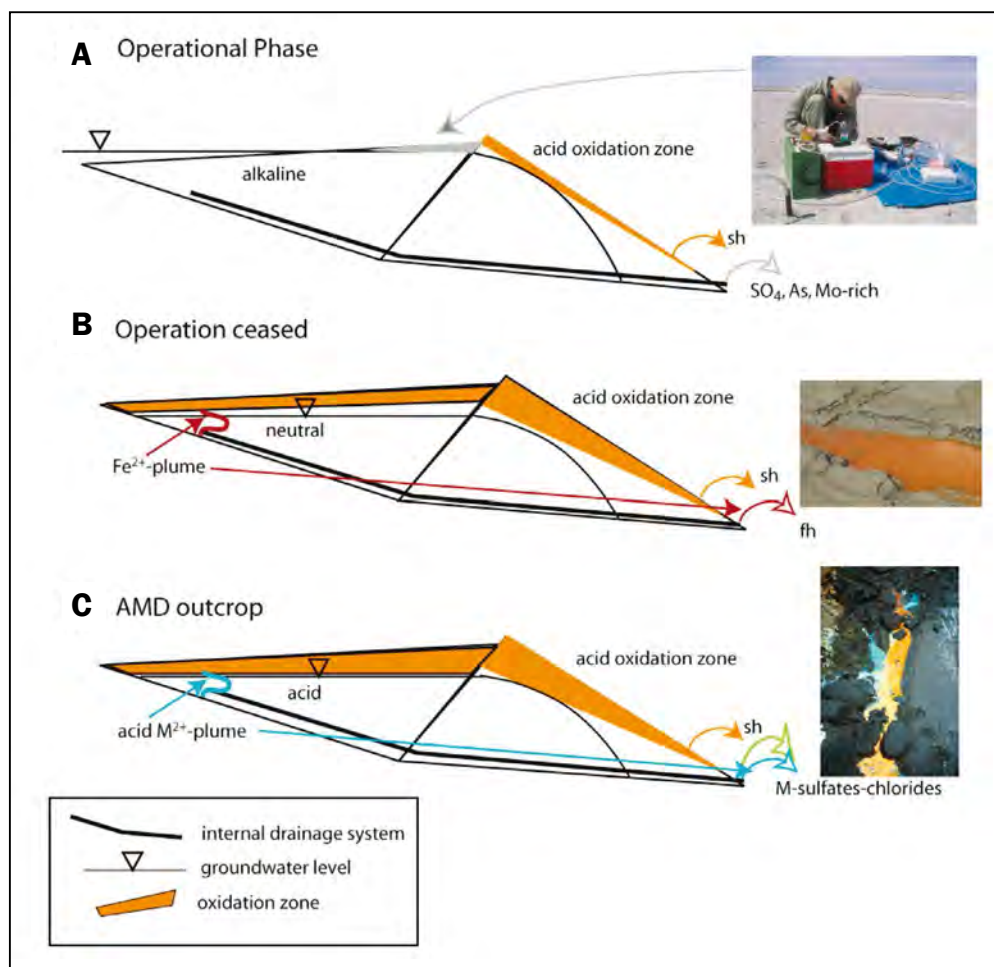


Figure 6. The tailings impoundment shown here is a modern design, with integrated basement impermeabilisation and internal drainage system. Most of the tailings impoundments around the world do not have impermeabilisation and the contaminated solution will directly infiltrate into the groundwater. (A) During the operational phase the system is saturated and alkaline. There might be increased concentrations of oxyanions depending on the mineralogy of the ore. If the dam is built with the coarse fraction of the tailings, oxidation and acidification might start during the operational phase with first signs of AMD (Sh). Surface precipitates are white at this stage. (B) After operation has ceased, an acid oxidation zone will develop and a ferrous iron plume below the oxidation front can migrate at neutral pH conditions in the tailings stratigraphy. This neutral, ferrous iron-rich plume will produce ferrihydrite (Fh) at its outflow. And (C) acid production due to sulphide oxidation continues and the neutralization potential will be completely consumed, resulting in an acid flow in the tailings mobilizing heavy metal cations and resulting in the formation of AMD with multi-colour precipitates (mainly metal sulphates and/or chlorides).

with the tailings from sulphide flotation, we add ferric iron to the sulphides and subsequently cover this sludge with more fresh tailings, so that they eventually end up in a reducing environment. Thus, the ferric iron from the sludge can oxidize the sulphides or undergo reductive dissolution; both processes will produce a ferrous iron plume (some times even acidic) in the tailings stratigraphy, which again will migrate down through the tailings stratigraphy of the active tailings impoundment. Therefore, even if we take (unrealistic) precautions to prevent sulphidic tailings from coming in contact with the atmosphere, eg, by maintaining a water saturated tailings impoundment, so that only minimum sulphide oxidation can occur, and we cover the tailings directly after the operation has ceased to prevent any further oxidation, the tailings impoundment will one day produce AMD, when the ferrous plume formed due to the addition of the ferric sludge flows out from the foot of the tailings dam.

With these examples we have learned, that we should not mix mine waste from different geochemical systems. Do not mix sulphides with Fe(III) hydroxide sludge in a tailings impoundment, or you will increase the volume of the waste and create adverse geochemical reactions, increasing your long-term environmental management costs. The same is the case for hazardous materials, containing problem elements in the form of oxyanions (eg, As, Mo, Cr, SO_4), as they should not be mixed with material that contains heavy metals (eg, Cu, Zn, Ni, Cd, Pb) due to the reverse sorption behaviour. Confine your reactive waste separately

in well-designed disposal facilities, so that the geochemical reactions can be controlled long-term and no hazardous elements can escape these systems to the hydrological system surrounding your operations. This will also help future generations to re-exploit these resources with better techniques than are available today.

Conclusions

Sulphide oxidation and the subsequent formation of acid mine drainage (AMD) in mine tailings impoundments is associated with a sequence of biogeochemical and mineral dissolution processes and can be classified in three main phases from the operational phase towards the final outcrop of AMD.

Operational phase of a tailings impoundment: neutral-alkaline oxyanions-rich effluents (Figure 6A)

During the operational phase of a sulphidic mine tailings impoundment, no sulphide oxidation should occur, when it is properly managed. This means it should be completely water saturated without exposure of the tailings to the atmosphere, and the system should maintain neutral to alkaline pH conditions (Figure 6A). If this is not the case, sulphide oxidation might start in the unsaturated parts of the tailings, as well as in the tailings dam, if it is built with the coarser fraction of the tailings themselves. This might lead to sulphide oxidation and AMD formation during the operational phase. In ore deposit types, which contain sol-

uble sulphate minerals like gypsum-anhydrite (eg, porphyry copper deposits), high SO_4 concentrations can be expected in the tailings controlled by the solubility of these minerals, with a typical range between 1 500 and 2 000 mg/L SO_4 .

Additionally, if the ore deposit shows some pre-oxidation naturally or due to the exploitation process, such as block-caving, elements like arsenic or molybdenum, which are adsorbed onto Fe(III)hydroxides, might be desorbed in the alkaline flotation circuit and maintain elevated concentrations in the active tailings impoundment and its effluents. These processes might lead to the need for implementation of sulphate treatment plants or a facility for Mo treatment as in the case of the Carén tailings impoundment from the El Teniente mine, Chile. Mine tailings should not be used as a general waste dump for other industrial waste material, as this might produce severe environmental risks for the whole system and importantly might increase the environmental waste management costs. The visible signs of this stage are usually white precipitates on the surface or around leachates (at this stage the patient is starting to feel bad and have some problems, he becomes pale, but there is still time for prevention).

After operation ceases; neutral ferrous plume outcrop (Figure 6B)

When the active operational phase ceases, no water and tailings are deposited, which will lead to a drop in the groundwater level in the tailings impoundment and produce an unsaturated zone, where atmospheric oxygen can start the process of sulphide oxidation. This will lead over several years to the formation of an acid oxidation zone, where heavy metals leach out and oxyanions like As and Mo are adsorbed onto the secondary Fe(III) hydroxides formed due to sulphide oxidation. Additionally, due to reduction processes at the oxidation front a ferrous iron plume is formed in the stratigraphy of the tailings impoundment. This ferrous plume can then migrate through the still neutral stratigraphy downwards through the tailings. Once this ferrous plume (which might contain high sulphate concentrations and other oxyanions like As and Mo in solution) outcrops at the foot of the dam for example, the ferrous iron will auto-oxidize due to the neutral pH and precipitate as ferrihydrite (Bordeaux red). This outcrop of the neutral ferrous plume is the first visible sign of the AMD formation process. With subsequent hydrolysis producing ferrihydrite, the effluent will be acidified and the final pH will depend on the buffering capacity of the effluent.

Now the patient has still increased blood pressure (visible red head) and needs help, for prevention it might be too late, most likely long-term treatment is needed. Only by drillings and piezometers can this stage be detected in the tailings stratigraphy in time (it is like taking the blood pressure, if there is no visible sign).

Final AMD appearance (acid flow, heavy metal-rich effluent; Figure 6C)

If sulphide oxidation continues and the neutralization potential of the underlying gangue mineralogy is consumed, an acid flow will become established in the tailings. This enables heavy metals like Cu, Zn, Ni, Pb, and Cd to be mobilised through

the tailings and outcrop at the foot of the dam or infiltrate into the groundwater, if no impermeable liners have been installed. The efflorescent salts resulting from this acid flow are brightly coloured, blue, green, yellow, white, or red depending on their elemental composition.

This is the final stage of AMD formation and the patient is now extremely ill (you can see it clearly in his green, yellow, blue face), where only final long-term treatment might mitigate the environmental damage. Prevention is here not possible any more, in some cases some drastic remediation with complete saturation of the system might help to alive the symptoms, if there is enough suitable water available [41,66] and the dam stability is not an issue.

Only proper studies can detect in time, at which stage an impoundment is present and predict how the evolution will continue. This is the key knowledge required in order to control and manage these systems properly long-term.

References

A list of references for this article is available from the editor at chemtech@crowm.co.za.

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Two overbelt magnets from Multotec delivered to coal mining application

Multotec's intimate understanding of minerals processing and handling applications, coupled with its flexibility in being able to offer its customers fit-for-purpose solutions, has resulted in a repeat order for two overbelt magnets sold into a coal mining application in the Witbank/Middelburg coalfields. "This order follows on from the successful commissioning two years ago of two overbelt magnets at another coal mine in the same group," Willem Slabbert, Process and Applications Manager at Multotec, says.

"Multotec has a good standing within the Witbank/Middelburg coalfields area, where our products are supported by our local branches," Slabbert says. Commenting on the latest order, he explains that the application is to remove tramp metal from run-of-mine material in order to prevent it from entering coal gasifiers.

"This is a critical application as the coal gasifiers have very stringent tramp metal removal specifications," Slabbert says. Tramp iron traditionally removed from coal carrying conveyors includes sections of continuous mine core breaker teeth, conveyor belt idlers, belt joints, wire, roof bolts, metal plates, slings, picks and pick cases, cable hooks, expanded metal, tools, tin cans and other such objects.

Multotec supplied the original two overbelt magnets in September 2012, with the latest order representing the second phase of an ongoing expansion project. Stuart Cullum, Process Engineer, explains that the width of the conveyor belts in this coal mining application is 1.8 m, with the overbelt magnets themselves being 5.1 m wide and 2.45 m high. They incorporate the latest technical specifications of the client, including pulley design, control and instrumentation.

The overbelt magnets are suspended over the conveyor on gantries for easy removal for maintenance purposes. Features include an automatic belt-driven self-cleaning system that dumps the tramp iron into collection bins at the side of the conveyor.

The latest two overbelt magnets were



Longi-Multotec overbelt magnets are designed according to specific applications criteria.



Longi-Multotec overbelt magnets are engineered to effectively remove even the most challenging tramp metal.

transported to Mpumalanga on lowbed trucks, and weigh 28 t each without cooling oil. The latter is added once on site using an oil tanker, with a final total weight of 33.7 t for each overbelt magnet. As per client safety specifications, the overbelt magnets have eight safety chains rated and certified for a load of 16 t each. This is double the normal requirement, with four chains rated at 8 t each being the norm.

Slabbert confirms that these are the largest overbelt magnets available in the Longi-Multotec range. "Through our partner-

ship with Longi, Multotec now has access to a comprehensive range of off-the-shelf air-cooled overbelt magnets for underground tramp metal removal, with the option of flame proofing." Having a standard range on hand means that Multotec can meet customer requirements far more quickly, as this reduces lead times significantly.

For more information contact Bernadette Wilson on tel: +27 11 923 6193, or email bernadettew@multotec.com, or go to www.multotec.com.

Giant leap in copper leaching technology

A new leaching technology from FLSmidth can increase copper output by 3 %, according to a recent report. That would mean an extra USD 40 million per year for an average copper mine with primary sulfide ore.

The top ore layer of an open pit copper mine is easily processed using heap leach in tandem with solvent extraction and electrowinning to produce copper cathodes. The

copper mineral most predominate in mines is however chalcopyrite (CuFeS_2), a refractory sulfide mineral that is found deeper in the mine. Consequently, mining companies struggle to maintain copper production during the transition from oxide ore to sulfide ore as open pit mines reach the later stages of development. Mining companies also struggle to recover the copper from very low-

grade concentrates and from concentrates contaminated with arsenic.

FLSmidth recently filed patents for a new hydrometallurgy process called the FLSmidth® Rapid Oxidative Leach that can economically remove the passivation layer of primary sulfides and thereby allow the extraction of copper. The technology operates at atmospheric pressure and temperature

Call to make tailings dams safer

Monitoring of tailings storage facilities could provide better levels of confidence that the facility is performing as was intended if regular monitoring data measurements were compared to expected values rather than just being checked for changes, according to two young engineers at SRK Consulting (SA).

In a presentation to the South African Young Geotechnical Engineers conference in Stellenbosch late last year, civil engineer Andrew Derrick and geotechnical engineer, Waldo Kruger argued that traditional monitoring techniques did not generate a tangible measure of 'degree of belief' - especially after a number of highly publicised tailings dam failures in recent years.

One of the factors behind this issue was that the regulated hazard profile for tailings dams was based on the Department of Water and Sanitation's protocol for the inspection of water retention dams.

"While the depth and volume retained by a water storage dam tends to remain relatively steady, the same cannot be said of a tailings dam," said Derrick and Kruger. "Tailings dams are constantly changing, and these changes are essentially detrimental; as they get higher, the potential risks increase and there is progressively more chance of operational errors."

These dangers are aggravated by the fact that the dams do not generate revenue directly to fund their own maintenance, and are often treated as an irritation by owners who are seldom familiar with the geotechnical aspects of these structures, they said.

To check on the stability of tailings dams, current monitoring practices include site inspections, meetings and analysis of material, geometric and climatic data - as well as checking on the seepage regime and the water table.

Standpipe piezometers are installed to



An aerial photograph taken of a tailings storage facility as part of an aerial inspection which forms part of an active monitoring program at the facility

measure water levels within the facilities, and these reflect the efficiency of the drainage system; large changes in the piezometric level, then, may indicate a possible blockage of drains.

"This information, however, is only a record of changes within the dam - implying some form of consistency or inconsistency," they said. "The readings are not compared to an expected value that measures the performance against the design."

So, while monthly drain flow measurements are useful for checking on individual drain performance, the information does not indicate the level of risk or the probability of failure.

"Monitoring programmes should be designed in such a way that field measurements are compared to anticipated performance," said Derrick and Kruger. "An investigation should be done into the establishment of a database of monitoring information, so that an empirical model could be developed from the data. Expected drain flows could then be obtained using empirical data."

They also argued for an analytical model that could be calibrated against the empirical model and the database; while admitting that this could be a difficult task, they were



Andrew Derrick, civil engineer and Waldo Kruger, geotechnical engineer, SRK Consulting (SA)

confident that this would allow for a more reliable quantifying of the risks inherent in tailings dams.

"In this way, a systems approach could be applied to the monitoring of tailings storage facilities, and this would enable owners, regulators and practitioners to re-assess our 'degree of belief' on an ongoing basis - instilling more confidence in our monitoring practices," they said.

For further information about FLSmidth, please visit www.flsmidth.com.

around 80 °C, making it possible to leach directly at the mine and hence provide a seamless transition from oxide ore to sulfide concentrates. While existing atmospheric leach processes leach a maximum of 95 % copper in 20-60 hours, the FLSmidth® Rapid Oxidative Leach process can leach more than 98 % of copper from concentrates containing as low as 8 % copper in less than 6 hours; a faster and much simpler process.

And that, as Head of Group R&D, Jens Almdal, points out is a giant leap in productivity improvements: "For a copper mine with remaining low quality copper deposits producing around 200,000 tons of copper per year, our 3% output increase would mean an extra USD 40 million per year with a copper price around USD 6 600 per ton. That is indeed

a significant contribution to profitability in an industry that normally chases 0,1-0,2 % increase in copper recovery by design modifications of flotation machinery," Jens Almdal states.

For copper producers, the new technology could mean a renewed business case for remaining deposits: several existing mines have lost the ability to make copper concentrates suitable for smelting. The FLSmidth® Rapid Oxidative Leach technology makes it possible to recover more copper from low grade concentrate. Also, there are mineral deposits yet to be developed that are unsuitable for smelting but with the new technology would be suitable for leaching.

The new technology also makes it possible to develop mineral deposits containing

arsenic for recovery of copper, gold and silver, while complying with stringent environmental air and land pollution regulations. As the new technology operates at atmospheric pressure, a concentrate can be treated at the mine location, with complete control over the arsenic-bearing residues generated after leaching. This makes it possible to avoid the potential of arsenic contamination of sea, air and land while en route from mine to smelter.

"A lot of existing mines have piles of copper concentrate with more than 0,5 % arsenic concentrations which is too high for smelting. Our technology can be used to process these piles of high arsenic concentrate or even make it possible to develop new mineral deposits high in arsenic," explains Manfred Schaffer, President, Minerals division.

Endress+Hauser showcases their laser technology

The Africa Automation Fair 2015 took place from 5 - 7 May 2015 at The Dome, Northgate, Gauteng. As a showcase for industrial control technologies, it is one of the biggest, most comprehensive shows of this type held in the southern hemisphere.

On Tuesday 5 May, 'ChemTech' attended a Laser Technology breakfast at the Africa Automation Fair as guests of Endress+Hauser. Laser technology is seen as a "real solution for industrial online gas applications". The company has recently strengthened its analytics business on a broad scale. SpectraSensors, a global leader in laser-based gas analysis with absorption spectroscopy, became part of the Endress+Hauser Group in 2012 and the following year, Kaiser Optical Systems, a pioneer in the field of RAMAN spectroscopy, was acquired.

Both companies will continue to operate as independent competence centres, but, because advanced analysis technologies are fast, reliable and highly precise and require no expendable materials and no special environmental conditions, they are cost-effective and low maintenance, thus driving down operational expenses. SpectraSensors' gas analysers are designed for process control and monitoring applications and the RAMAN instruments from Kaiser Optical systems are used in production as well as in the lab.

To tell us all about the technologies were visitors to South Africa, Koen Roelstraete, Director of International Sales at SpectraSensors, and Dr Peter van Vuuren, respon-

sible for worldwide business development for the laser-based Optograph Process RAMAN analyzer product line manufactured by Kaiser Optical systems Inc.

After a welcome by Rob MacKenzie, Managing Director of Endress+Hauser, Mr Roelstraete gave us an historical overview of the Tunable diode laser absorption spectroscopy (TDLAS) technology which delivers fast and accurate gas analysis measurements. The products are used in natural gas production, transport, storage, distribution, gas processing, refining, petrochemical, and specialty and bulk gas production. The analyzers measure Moisture (H₂O), Carbon Dioxide (CO₂), Hydrogen Sulfide (H₂S), Ammonia (NH₃), Acetylene (C₂H₂), Oxygen (O₂). The headquarter is located in Houston, Texas with production facilities in Rancho Cucamonga, California. For more information on the company and the offering please visit www.spectrasensors.com.

Kaiser Optical Systems, Inc's principal products include Raman sensors and instrumentation and advanced holographic components for spectroscopy, telecommunications, astronomy and ultra-fast sciences. Off-the-shelf and customized solutions for end-users and OEMs are available. The special qualities of the Optograph chromatograph are that no valves, columns, carrier gas or instrument air are required. For more information on the company and the offering please visit www.kosi.com.

Acquisitions reinforce the position of



the Endress+Hauser Group and expand its fields of activities as well as supporting clients with solutions and services for industrial process engineering. Related companies expand the company's product range with know-how in areas of lab-analytcs, and advanced analyser systems for liquids, solids and gases as well as energy consulting and sensor technologies.

For more information, contact Kgomoitso Makhobela, Endress+Hauser, on tel +27 11 262 8000, or email info@za.endress.com

Chemical Technology is the only publication in Africa for chemical engineers focusing on all unit operations in a comprehensive way



SUDOKU NO. 105

Complete the grid so that every row across, every column down and every 3x3 box is filled with the numbers 1 to 9. That's all there is to it! No mathematics are involved. The grid has numbers, but nothing has to add up to anything else. You solve the puzzle with reasoning and logic. For an introduction to Sudoku see <http://en.wikipedia.org/wiki/Sudoku>

1	2							
		4						
5	3			4	6			8
	8					4		
			1			3	7	
		6					1	
			9	2				5
9					3	7		
	4		8					

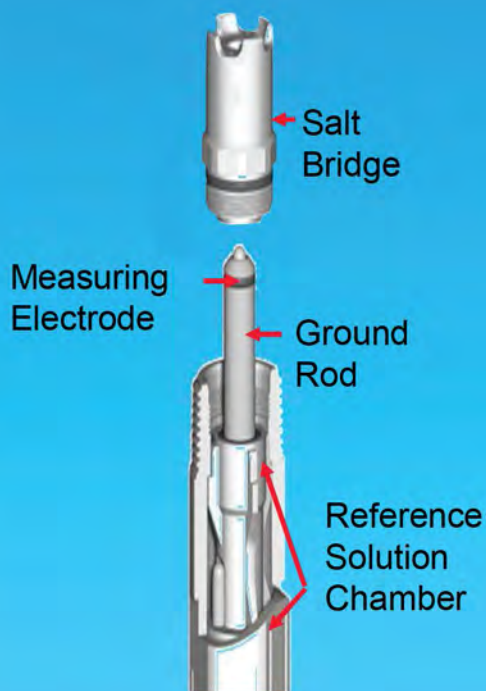
**Solution
for SUDOKU
104**

2	7	6	5	1	3	9	8	4
5	4	9	6	2	8	1	3	7
1	8	3	7	9	4	6	5	2
3	2	7	1	5	9	8	4	6
9	5	8	3	4	6	2	7	1
6	1	4	8	7	2	3	9	5
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4	9	1	2	8	7	5	6	3

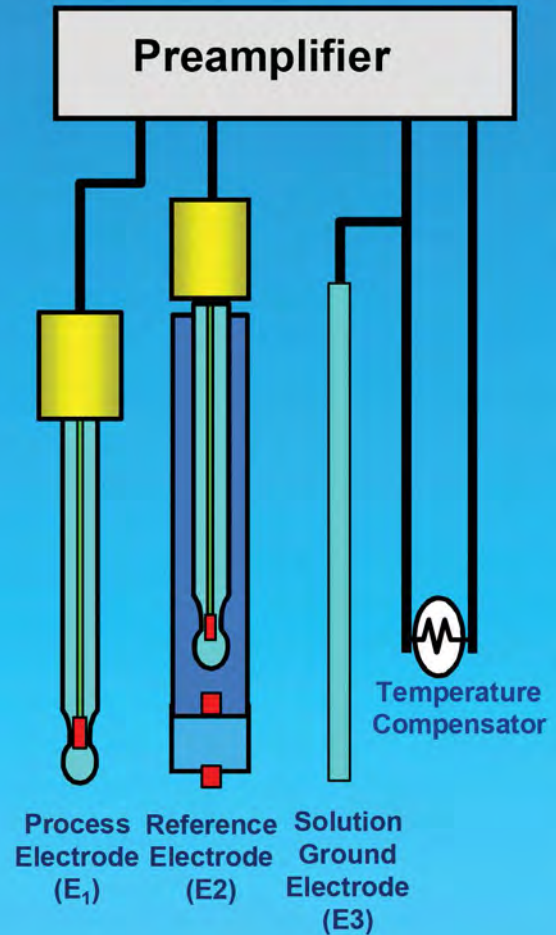
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