The Sequestration of Heavy Metals Contaminating the Wonderfonteinspruit Catchment Area using Natural Zeolite

P.P. Diale, S.S.L. Mkhize, E. Muzenda, and J. Zimba

Abstract—For more than 120 years, gold mining formed the backbone of South Africa’s economy. The consequence of mine closure was observed in large-scale land degradation and widespread pollution of surface water and groundwater. This paper investigates the feasibility of using natural zeolite in removing heavy metals contaminating the Wonderfonteinspruit Catchment Area (WCA), a water stream with high levels of heavy metals and radionuclide pollution. Batch experiments were conducted to study the adsorption behavior of natural zeolite with respect to Fe²⁺, Mn²⁺, Ni²⁺, and Zn²⁺. The data was analysed using the Langmuir and Freundlich isotherms. Two kinetic models namely, pseudo-first order and pseudo second order were also tested to fit the data. Pseudo-second order equation was found to be the best fit for the adsorption of heavy metals by natural zeolite. Zeolite functionalization with humic acid increased its uptake ability.

Keywords—gold-mining, natural zeolites, water pollution, West Rand.

I. INTRODUCTION

Gold (Au) mining extraction occurs from relatively narrow bands of quartzitic reefs, which were previously deposited as fluvial sediments in river deltas at the shores of an ancient inland lake [1]. In the case of uraniumiferous ores, the Au content in the ore is relatively lower compared to that of uranium (U) (i.e. about Au-U ratio 1:100), therefore large amounts of U and other heavy metals are brought to the surface by Au mining operations. Since mining is a transitory use of land that requires disruption or disturbance to provide essential mineral and energy [2]: land, hydrological, and air effects are always forthcoming. Acid mine drainage (AMD) is the most well documented type of water pollution. Batch experiments were conducted to study the adsorption behavior of natural zeolite with respect to Fe²⁺, Mn²⁺, Ni²⁺, and Zn²⁺ better, with the adsorption capacity of 11.9 mg/g, 1.2 mg/g, 1.3 mg/g, and 14.7 mg/g, respectively. Two kinetic models namely, pseudo-first order and pseudo second order were also tested to fit the data. Pseudo-second order equation was found to be the best fit for the adsorption of heavy metals by natural zeolite. Zeolite functionalization with humic acid increased its uptake ability.

In the first step, pyrite reacts with oxygen and water producing Fe²⁺ and sulphuric acid by reaction (1). The second step has the oxidation of Fe²⁺ to Fe³⁺ by reaction (2), which is pH-dependent. The third step corresponds to the hydrolysis of Fe³⁺ with water to form a ferric hydroxide precipitate and the release of additional acidity, which is promoted by the pH-dependent reaction (3). The fourth step is defined as the oxidation of additional pyrite by Fe³⁺ according to reaction (4). The pyrite oxidation process is controlled by bacterial species that have definite pH growth range and pH growth optimum [3]. The conversion of Fe²⁺ to Fe³⁺ has been described as the rate limiting step, however the presence of bacteria such as Acidithiobacillus ferroxidans is known to accelerate this reaction greatly. Acidithiobacillus ferroxidans is a common pyrite oxidizing bacterium and is the driving force behind the extensive acid and metal pollution generated when it releases metals from acid mine water [4].

A number of studies have been conducted using zeolites for removing heavy metals contaminating lake, streams, and dams [5], [6], and [7]. Zeolite was found to be effective in removing Pb²⁺ and Zn²⁺ from industrial wastewater at a pH of 7 [8]. Also zeolite has been found to be potentially effective for treating AMD [9], [10], [11], and [12]. Zeolites represent an appropriate material for removing heavy metal ions from water streams, because of its cation exchange characteristic.

The net negatively charged structure, which results from isomorphic substitution of Al³⁺ and Si⁴⁺ ions of the tetrahedral, with exchangeable cations such as Ca²⁺, Na⁺, or K⁺ located in the cavities and channels within it, give zeolite its most valuable characteristic [13]. Zeolites are also characterized by large void volumes (20% - 50%) and large internal surface areas of several hundred square meters per gram [14], [15], [16], and [17]. The amount of metals removed by zeolite is affected by the free energy of hydration of the cations, the valence of the cations, the molecular size and hydrated radius of cations [18] and [19]. Taking into consideration these characteristics, we focus our attentions to the use of sorption isotherms and kinetic models to determine the efficacy of natural zeolite in treating heavy metal contaminated water bodies of the Wonderfonteinspruit Catchment Area (WCA).

II. MATERIALS AND METHODS

The zeolite-rich samples from volcanic tufts of Heidelberg area, Western Cape, South Africa, were examined by scanning electron microscopy (SEM), X-ray diffraction (XRD), X-ray fluorescence (XRF), N₂-porosimetry in combination with Fourier transform infrared (FTIR) spectroscopy. Prior to all analyses, the samples were pulverized and dried. A Leica-Cambridge Scanning Electron Microscope (Model S420-1) was used to study the surface morphology of the zeolite. X-ray powder diffraction patterns were obtained using a Siemens D500 diffractometer, with Ni-filter, Cu Kα radiation, operating at 40 kV, 30 mA. A step size of 0.02° 2θ and a counting time of 4 second per step were applied over a range of 3° to 90° 2θ. X-ray fluorescence analysis were carried out with the use of

FeS₂ + 3.5O₂ + 2H₂O → FeSO₄ + H₂SO₄
4Fe³⁺ + 1/2 O₂ + 4H⁺ → 4Fe²⁺ + 2H₂O
4Fe³⁺ + 12H₂O → 4 Fe (OH)₃(s) + 12H⁺
FeS₂(s) + 14Fe³⁺ + 8H₂O → 15Fe²⁺ + 2SO₄²⁻ + 16H⁺
an ARL Advant XP sequential (wavelength dispersive) XRF.
Nitrogen adsorption measurements were performed with a Micromeritics ASAP 2010 surface area analyzer. For the adsorption-desorption curves the adsorbate was N₂ and pore size distribution was calculated from the desorption branch using the Barret-Joyner-Halenda (BJH) model. The pre-treatment, which involves the degassing procedure of the samples, took place under the temperature of -195.85 °C. IR absorption measurements were carried out using a FTIR Perkin Elmer 880. The FTIR spectra in the wavelength ranged from 400 cm⁻¹–5000 cm⁻¹.

Adsorption experiments for metals Fe²⁺, Mn²⁺, Ni²⁺, and Zn²⁺ were carried out with 0.5 g initial mass of zeolite material, at initial pH values of 2.4 and at different initial metal concentrations: 5, 10, 25, 50, 100, and 130 mg/L. Tests were run for 120 minutes on an orbital shaker, enough time to reach equilibrium and all samples were analysed with an Atomic Absorption Spectrophotometer (AAS). The experimental design is summarised in Table 1.

The experimental results were fitted to the Langmuir and Freundlich sorption isotherm models. For the purpose of comparative study, the natural zeolite material was functionalized with humus, consisting of 20% humic acid and 2% fulvic acid. Humic substances are chemically complex materials that have the capacity to remove metals from solutions. They contain carboxylic groups, phenolic and alcoholic hydroxyls, ketones and quinine groups, which all can react with metal and subsequently remove them from solutions. The process of zeolite functionalization is to introduce some if not all the groups found in the humic material, with an aim to improve its heavy metal removal capacity. Natural zeolite of 200 g mass was mixed with humic acid (20%) 250 ml in a 500 mL glass beaker. The mixture was stirred on a magnetic plate for 24 hours, filtered and washed before it was dried in an oven for 24 hours. The Fourier Transform Infrared (FTIR) was used to determine the extent of the functionalization of the zeolite material.

III. RESULTS AND DISCUSSION

3.1 Characterisation of natural zeolite

The electron scanning was used to study the surface morphology of the zeolite material. Several large crystals together with amorphous materials formed a large pore mouth in Fig 1, depicting a heulandites group crystal complex. Thin platy crystals “coffin-shaped” ones indicate that the HEU type zeolite is not crystalized uniformly and that discrete crystals of heulandites and of clinoptilolite are mixed together contributing to what is macroscopically determined as “heulandites type-II” [20].

The main zeolite mineral belongs to the heulandites group. The (020) reflection of heulandites, at 9.98 Å is always far more intense than the remaining lines of the pattern, while the respective reflection of clinoptilolite, is found at about 3.98 Å. The indices of refraction and birefringence of heulandite type zeolites decrease with substitution of Na and Si for Ca and Al. Clinoptilolite has near = 1.476 – 1.491, nβ = 1.479 – 1.493, nγ = 1.479 – 1.497, δ = 0.003 – 0.006 and 2Vx = small to large [21].

The elemental analysis by X-ray fluorescent (XRF) was used to distinguish whether the natural zeolites were heaulandite or clinoptilolite type zeolites and whether they were hydrophobic or hydrophilic, a summary of these results are shown in Table 2.

![Fig. 1 SEM picture of Jadico zeolitic tuff](image)

The results showed that the zeolite sample had a high silicon composition compared to aluminium. Potassium (K) and calcium (Ca) were the major single extra-framework cations in natural. According to IMA CONMMN’s third rule, only heulandite and clinoptilolite zeolites can solely be distinguished on the basis of the silica and aluminium framework [22]. Heulandite has a Si/Al ratio of less than 4, whilst clinoptilolite has a Si/Al of equal or more than 4. The Si/Al ratio is 6.6 (mol/mol). The chemical composition, the theoretical exchange capacity, and the Si/Al ratio, generally ranging from 4 to 6.8, are typical for clinoptilolite. Low-silica members are enriched with potassium, sodium, and magnesium. The advantage of

<table>
<thead>
<tr>
<th>Inorganic salts</th>
<th>Concentration (mg/L)</th>
<th>pH</th>
<th>Agitation (rev/min)</th>
<th>Zeolite (g)</th>
<th>Vol. (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc Chloride (ZnCl₂)</td>
<td>6.9</td>
<td>2.4</td>
<td>180</td>
<td>0.5</td>
<td>50</td>
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<tr>
<td>Iron Sulphate (Fe₂SO₄)</td>
<td>115</td>
<td>2.4</td>
<td>180</td>
<td>0.5</td>
<td>50</td>
</tr>
<tr>
<td>Manganese Sulphate (Mn₂SO₄)</td>
<td>121</td>
<td>2.4</td>
<td>180</td>
<td>0.5</td>
<td>50</td>
</tr>
<tr>
<td>Nickel Sulphate (NiSO₄)</td>
<td>26.5</td>
<td>2.4</td>
<td>180</td>
<td>0.5</td>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>K₂O</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>TiO₂</th>
<th>Si /Al</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.8</td>
<td>2.7</td>
<td>2.0</td>
<td>1.3</td>
<td>0.7</td>
<td>0.1</td>
<td>6.59</td>
<td>Ata et al., 1994</td>
</tr>
<tr>
<td>77.96</td>
<td>13.17</td>
<td>2.20</td>
<td>1.06</td>
<td>3.80</td>
<td>0.08</td>
<td>5.92</td>
<td>Ören et al., 2005</td>
</tr>
<tr>
<td>63.74</td>
<td>11.80</td>
<td>2.46</td>
<td>1.66</td>
<td>1.86</td>
<td>5.40</td>
<td>5.45</td>
<td>Elaiopolous et al., 2007</td>
</tr>
<tr>
<td>73.6</td>
<td>13.5</td>
<td>4.24</td>
<td>1.60</td>
<td>3.65</td>
<td>5.45</td>
<td>5.45</td>
<td>Ríos et al., 2008</td>
</tr>
</tbody>
</table>

![Table I: Experimental Program for Examining the Metal Adsorptivity by Natural Zeolite](image)

<table>
<thead>
<tr>
<th>Table II: Elemental Analysis Results of Jadico Zeolite Tuff</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>Al₂O₃</td>
</tr>
<tr>
<td>58.75</td>
<td>24.31</td>
</tr>
</tbody>
</table>

![Table II](image)
high Si/Al ratios is that in low pH environments, the structure is less likely to be damaged. The pore size distribution (PSD) was estimated using Barret-Joyner-Halenda (BJH) model and Table 3, shows the results.

**Table III**

<table>
<thead>
<tr>
<th>Sample</th>
<th>BJH Desorption average pore diameter (nm)</th>
<th>BET surface area (m²/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jadico</td>
<td>10.36</td>
<td>65.48</td>
</tr>
</tbody>
</table>

The adsorption/desorption isotherm curves were used for determine the pore morphology of the difference zeolite material. Specific surface area was estimated using the Brunauer-Emme-Teller (BET) equation isotherm. According to literature, common industrial adsorbents like activated carbon have surface areas in the range of 500 m²/g – 2000 m²/g, with polymeric adsorbents having 150 m²/g – 1000 m²/g. For the natural zeolite analysed the surface areas was found to be 65.48 m²/g. The surface area is lower than those of adsorbents currently used in the catalysis industry. This could imply that the use of natural zeolites in such applications may not be ideal.

The vibration in the region 1600 cm⁻¹ – 3700 cm⁻¹ can be assigned to the presence of zeolite water. The isolated OH⁻ stretching (3634.2 cm⁻¹) is attributed to interaction between the water hydroxyl and the cations present [23].

### 3.2 Adsorption study

The sorption data was subjected to different sorption isotherms, namely, Langmuir and Freundlich. The equilibrium data for metal cations over the concentration range from 10 mg/L – 130 mg/L at room temperature have been correlated with these isotherms. A linear plot is normally obtained when \( Ce/Qe \) is plotted against \( Ce \) over the entire concentration range of metal ions investigated, and this is illustrated in Fig. 3. The Langmuir model was derived on assumptions that: (i) maximum adsorption corresponds to a saturated monolayer of adsorbate molecule on the adsorbent surface; (ii) the adsorption sites and reactions have a constant free-energy change \( (\Delta G_{ads}) \) for all and (iii) there is no transmigration of adsorbate in the plane of the surface [24]. With Langmuir two parameters will be analysed to evaluate the efficiency of the system: \( Q_m \), maximum adsorption capacity (mg/g) and \( b \), the energy of adsorption (L/mg). This model has the form as follows:

\[
Qe = Q_m \frac{bCe}{1 + bCe} \tag{5}
\]

\[
\frac{Ce}{Qe} = \frac{1}{Q_m b} + \frac{Ce}{Q_m} \tag{6}
\]

Where \( Qe \) (mg/g) is the amount adsorbed at equilibrium and \( Q_m \) (mg/g) is the Langmuir constant, which is equal to the adsorption

![Fig. 2 FTIR spectrum of the Jadico zeolitic tuff](image-url)
capacity. The parameter $b$ represents the Langmuir sorption equilibrium constant, and $C_e$ (mg/L) is the equilibrium concentration.

The Langmuir model parameters and the statistical fits of sorption data to the isotherm equation are given in Table 4. The Langmuir model described the sorption data for all the cations with $R^2$ value > 0.9, except for Fe$^{2+}$.

According to the $Q_{max}$ (mg/g) parameter, sorption on zeolite is produced following the sequence: Zn$^{2+}$ > Fe$^{2+}$ > Mn$^{2+}$ > Ni$^{2+}$. Zeolites are generally weakly acidic in nature and sodium-form exchangers are selective for hydrogen, which leads to high pH values when the exchanger is equilibrated with relatively dilute electrolyte solutions [25]. This then makes the metal hydroxide precipitation feasible. In natural zeolites these metals seem to reach saturation, which means that the metal had filled possible available sites and further adsorption could take place only at new surfaces [26].

Alternatively, the Freundlich equation is empirical and is among the earliest empirical equations that can be employed to predict adsorption equilibria data. The Freundlich isotherm is based on these assumptions: (i) the adsorbent has a heterogeneous surface energy, where different sites could have different site energies, as opposed to the Langmuir assumption of constant site energy; (ii) the site energies for adsorption follow a Boltzmann distribution and the mean site energy $= \Delta H^{\circ}_{mod}$ and; (iii) the change in adsorption site entropy increases linearly with increase site enthalpy ($-\Delta S^{\circ}_{mod}$) [27].

The Freundlich equation can be written in the following form:

$$\log Q_e = \log K_f + \frac{1}{n} \log C_e \quad (7)$$

Where, $K_f$ and $n$ are the Freundlich constants. The parameter $K_f$ indicates the Freundlich adsorption capacity, while the parameter $n$ characterizes the heterogeneity of the system. The parameter $n$ is usually greater than unity. A larger $n$ value, means that the system is more heterogeneous, which usually results in non-linearity of the adsorption isotherm. The Freundlich sorption isotherm was applied to the removal of Fe$^{2+}$, Mn$^{2+}$, Ni$^{2+}$ and Zn$^{2+}$. The ability of the model to fit the experimental data was examined and a typical plot, as shown in Fig 4, was obtained for all metals investigated. The constants $K_f$ and $n$ were calculated for each cation (Table 4). This isotherm does not predict any saturation of the sorbent by the sorbate, thus infinite surface coverage is predicted mathematically, indicating multilayer adsorption on the surface [23]. The ion exchange capacity of heavy metal cations is listed in Table 4 indicates the following selectivity sequence: Ni$^{2+}$ > Mn$^{2+}$ > Zn$^{2+}$ > Fe$^{2+}$. The heavy metal cations are present as hexaqua complex ions with six surrounding water molecules in the solution and pass through the zeolite framework in this form [28].

### Table IV Langmuir and Freundlich Isotherms Parameters

<table>
<thead>
<tr>
<th>Metal</th>
<th>$R^2$</th>
<th>Estimated Parameters</th>
<th>Freundlich Isotherm Model</th>
<th>Estimated Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe$^{2+}$</td>
<td>0.8456</td>
<td>$Q_m = 11.933$ (mg/g)</td>
<td>$K_f = 0.1874$ (mg/g)</td>
<td>$n = 1.149$</td>
</tr>
<tr>
<td>Mn$^{2+}$</td>
<td>0.9917</td>
<td>$Q_m = 1.3126$ (mg/g)</td>
<td>$K_f = 0.126$ (mg/g)</td>
<td>$n = 1.4535$</td>
</tr>
<tr>
<td>Ni$^{2+}$</td>
<td>0.9362</td>
<td>$Q_m = 1.286$ (mg/g)</td>
<td>$K_f = 0.232$ (mg/g)</td>
<td>$n = 2.192$</td>
</tr>
<tr>
<td>Zn$^{2+}$</td>
<td>0.9157</td>
<td>$Q_m = 14.728$ (mg/g)</td>
<td>$K_f = 0.5756$ (mg/g)</td>
<td>$n = 1.286$</td>
</tr>
</tbody>
</table>

### 3.3 Kinetic study

Two kinetic models were applied to evaluate the experimental data and results. The pseudo-first-order kinetic model for the adsorption of liquid/solid system is based on solid uptake capacity. This model assumes that the rate of uptake with time is directly proportional to the difference in the saturation concentration and the amount (cumulative) of solute uptake with time. The general equation is expressed as:

$$\log Q_e = \log K_f + \frac{1}{n} \log C_e$$
Where $Q_e$ and $Q$ are the amounts of metal ions adsorbed on the adsorbent (mg/g) at equilibrium and at time $t$, respectively, and $k$ is the pseudo-first order adsorption rate constant (min$^{-1}$). Integrating equation (8) for the boundary condition $t = 0$ to $t = t$ and $q = 0$ to $q = q_t$, the linear form of the equation becomes,

$$\ln(Q_e - Q) = \ln Q_e - kt$$

(9)

The plot of $\ln(Q_e - Q)$ vs $t$ would be a straight line with its slope giving the value of specific rate constant. The pseudo-second-order kinetic model is based on the amount of adsorbate on the adsorbent. If the rate of adsorption is a second order mechanism, the pseudo-second-order chemisorption kinetics rate equation is expressed as:

$$\frac{dQ}{dt} = k(Q_e - Q)^2$$

(10)

where $k$ is the second-order adsorption rate constant (g mg$^{-1}$ min$^{-1}$). Integrating equation (10) between the same limits, the linear form of the equation is written as:

$$t = \frac{1}{Q} + \frac{1}{Q_e} t$$

(11)

The plot between $t/Q$ vs $t$ will be a straight line with its slope and intercept helping to find the specific rate constant. The specific rate constant, determining the affinity for metal uptake, is directly proportional to the amount of metal ions adsorbed ($Q_e$) by zeolite. The $Q_e$ value obtained from plots should be the same as the $Q_e$ attained from kinetic models, in order for the model to be satisfied. The $Q_e$ calculated values, obtained from of pseudo-first-order kinetic model were extremely low and values are also fairly low when compared with the $Q_e$ experimental values for both natural and functionalized zeolite, see Table 5. The correlation coefficients for the pseudo-second-order kinetic model were more than 0.99 for all natural and functionalized zeolite and the theoretical metal capacity ($Q_t$) values agreed well with the experimental metal capacity ($Q_e$) values. This model is based on the assumption that the rate limiting stage can be a chemical adsorption involving valence forces through sharing or exchange of electrons between adsorbent and adsorbate. This appears to provide the best correlation of the obtained data. The kinetic data for the adsorption process illustrated in Figs 5(a) and (b), show that adsorption rate after humic acid functionalization is clearly higher for iron and manganese except for nickel and zinc.

Table V

<table>
<thead>
<tr>
<th>Zeolite</th>
<th>Pseudo-first-order model</th>
<th>Pseudo-second order model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$K_1$ (mg/g) $Q_e$ (mg/g) $R^2$</td>
<td>$K_{i_2}$ (mg/g) $Q_e$ (mg/g) $R^2$</td>
</tr>
<tr>
<td>Natural</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe$^{2+}$</td>
<td>0.004</td>
<td>2.19</td>
</tr>
<tr>
<td>Mn$^{2+}$</td>
<td>0.001</td>
<td>0.84</td>
</tr>
<tr>
<td>Ni$^{2+}$</td>
<td>0.004</td>
<td>0.408</td>
</tr>
<tr>
<td>Zn$^{2+}$</td>
<td>0.001</td>
<td>0.126</td>
</tr>
<tr>
<td>Functionalised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe$^{2+}$</td>
<td>0.005</td>
<td>1.535</td>
</tr>
<tr>
<td>Mn$^{2+}$</td>
<td>0.001</td>
<td>0.884</td>
</tr>
<tr>
<td>Ni$^{2+}$</td>
<td>0.009</td>
<td>0.396</td>
</tr>
<tr>
<td>Zn$^{2+}$</td>
<td>0.02</td>
<td>0.491</td>
</tr>
</tbody>
</table>

Better results appear to be due to humic acid treatment that changes substantially the chemical composition of the treated zeolite for all heavy metals. The kinetic uptake ($Q_e$) followed the sequence: Fe$^{3+}$ > Mn$^{2+}$ > Ni$^{2+}$ > Zn$^{2+}$; for natural zeolite and Fe$^{2+}$ > Mn$^{2+}$ > Zn$^{2+}$ > Ni$^{2+}$; for functionalized zeolite. The sequence of kinetic rate ($k$) showed a similar trend.
IV. CONCLUSION

• The natural zeolitic tuff, Jadico, from the Western Cape, South Africa was found to belong to the clinoptilolite group zeolite.
• The sorption isotherms of Fe$^{2+}$, Mn$^{2+}$, Zn$^{2+}$, and Ni$^{2+}$ fitted the Langmuir model. The metal uptake sequence was obtained as: Zn$^{2+}$ > Fe$^{2+}$ > Mn$^{2+}$ > Ni$^{2+}$. Zinc had the highest maximum metal uptake at (14.728 mg/g). According to the equilibrium constant, the affinity of metals for the metal removal followed the sequence: Zn$^{2+}$ > Fe$^{2+}$ > Mn$^{2+}$ > Ni$^{2+}$.
• The sorption of iron, manganese, nickel and zinc with natural and functionalized zeolite, fitted linearly to the pseudo-second order kinetic model, indicating that the process occurred in at least two steps. Zinc had the fastest sorption kinetic for both natural and functionalized zeolite. However, iron had the highest metal uptake.
• The natural zeolite functionalization by treating it with humic acid increased its uptake ability significantly for iron, manganese and not for zinc and nickel.

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REFERENCES


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He joined the University of Johannesburg, Johannesburg, South Africa on the 1st of November 2007. He has more than 15 years experience in academia which he gained at different Institutions: National University of Science and Technology Bulawayo, University of Birmingham, Bulawayo Polytechnic, University of Witwatersrand and University of Johannesburg. He is a recipient of several awards and scholarships for academic excellence. His research interests and area of expertise are in phase equilibrium measurement and computation, energy and environment, separation processes and mineral processing.

He has published more than 60 international peer reviewed papers in international scientific journals and conferences. His publications are mainly on measurement and computation of phase equilibrium using group contributions methods, static headspace and the dynamic GLC technique; flotation studies-effect of water quality, microwave pretreatment, pH; Leaching behaviour of copper bearing mattes; wastewater treatment, the characterization of South African zeolites for industrial and environmental applications and

Josephat Zimba is the General Manager for Salene Technologies, South Africa. Prior to that, he worked in the Advanced Materials Division at Mintek (South Africa) initially as a Senior Engineer and subsequently as a Principal Engineer. He holds a Doctorate in Physical Metallurgy and has nearly 15 years international experience in the field of Metallurgical/Materials Engineering. Josephat is a member of the Southern Africa Institute of Mining and Metallurgy and the USA Materials Research Society. In addition, he is a Fellow of the Zimbabwe Academy of Sciences and the current President of the Africa Materials Research Society.