Systematic characterization of the mixing process for the BIOX® reactor

R. VAN DEVENTER*, W. KELLER†, M. OOSTHUIZEN‡, and J. STAPELBERG§

*Gold Fields Mining Services, Johannesburg, South Africa, †Ekato RMT GmbH, Schopfheim, Germany, ‡Ekato Corporation, Oakland, NJ USA, §Ekato Africa, Johannesburg, South Africa

The BIOX® process was developed for the biological pre-treatment of refractory gold ores and concentrates ahead of conventional cyanide leach gold recovery. Rights to the process are currently with BIOMIN Technologies SA, a subsidiary of Gold Fields Limited. There are currently eight operating installations worldwide employing the process on a commercial scale. EKATO is a company specializing in developing new or optimizing existing mixing applications. EKATO has acquired a vast amount of expertise in agitation over its 75 year history.

In a joint research project the reactors of the BIOX® process were characterized from the aspect of their mixing performance. BIOMIN is constantly testing new mixing solutions and reviewing potential vendors to increase the efficiency of the BIOX® process. EKATO’s intention was to qualify as an approved vendor for supplying agitation equipment to the BIOX® process. A two step approach was planned: In phase one of the project EKATO would develop an alternative agitation solution to the established option, exhibiting at least similar performance levels. In phase two potential possibilities to improve the overall design would be developed.

This paper focuses on phase one and addresses the systematic approach applied by EKATO in characterizing the mixing processes. Mixing tasks were assessed individually applying basic theory and scale-up and -down rules to the individual tasks. Testing with model systems was done at the EKATO technology center in Schopfheim, Germany, on scales of 50 liters and 1 m³.

The results showed that the ISOJET-B impeller design showed promising performance under BIOX® reactor conditions. Scale-up with the ISOJET-B was done in order to apply it in the 21 m³ live volume test reactor at Fairview mine in South Africa. At Fairview tests were performed using model systems and eventually under real plant conditions with BIOX® slurries. The results were a success and confirmed that the scale-up factors determined during the testing at EKATO’s technology center could be substantiated in the ‘model scale’ 25 m³ reactor. Testing under the actual process conditions showed that all design parameters were within the desired range to be considered an excellent leaching performance.

This successful joint development shows the importance of a close cooperation of technology licensors or end-users and equipment suppliers. It is vital for understanding all factors influencing the mixing performance of processes. Exercises such as this will provide equipment suppliers and plant operators more confidence in managing further scale ups at ever larger engineered plants.
Introduction

The BIOX® process was developed for the biological pretreatment of refractory gold ores and concentrates ahead of conventional cyanide leach gold recovery. Rights to the process are currently with BIOMIN Technologies SA, a subsidiary of Gold Fields Limited. There are currently eight operating installations worldwide employing the process on a commercial scale. EKATO is a company specializing in developing new or optimizing existing mixing applications. EKATO has acquired a vast amount of expertise in agitation over its 75 year history.

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The BIOX process

The BIOX® plant typically consists of six equidimensional reactors configured as three primary reactors operating in parallel followed by three secondary reactors operating in series. The feed concentrate from the stock tank is diluted to 20% solids by mass before being fed to the primary BIOX® reactors. The operating slurry solids content is determined primarily by the sulfide content of the concentrate feed and the rate of oxygen transfer necessary to maintain the required rate of oxidation. The slurry solids content is also determined by the amount of toxic elements present in the slurry fed to the BIOX® reactors.

The pulp residence time in the bio-oxidation reactors is typically four to six days depending on the oxidation rates achieved, which is a function of the sulphide/sulphur content and mineralogical composition of the concentrate. Generally, half of the retention time is spent in the primary reactors to allow a stable bacterial population to be established and to prevent bacterial washout. Once a stable bacterial population has been established, a shorter retention time can be tolerated in the secondary reactors where sulphide sulphur oxidation is completed.

Nutrients in the form of nitrogen, phosphorous and potassium salts are also added to the primary reactors to promote bacterial growth. The mixed culture of mesophilic bacteria used in the BIOX® process can operate at temperatures ranging from 30°C to 45°C. The pulp temperature in commercial reactors is controlled between 40°C and 45°C. This temperature allows maximum sulphide oxidation rates to be achieved while minimizing cooling requirements. The oxidation of sulphide minerals is an exothermic process and the reactors must be cooled continuously by circulating cold water through a series of cooling coils installed inside the reactors.

Low-pressure air is injected into the BIOX® reactors to supply oxygen for the oxidation reactions. It is extremely important that a dissolved oxygen concentration of > 2 ppm be maintained at all times in the slurry. Axial flow fluid foil impellers are used in the BIOX® reactors they offer improved efficiency over radial-flow turbines. Figure 1 shows the typical BIOX® process flowsheet.
Objectives and developments

A systematic approach was applied by EKATO in characterizing the mixing processes. Mixing tasks were assessed individually applying basic theory and scale-up and -down rules to the individual tasks. Testing with model systems was done at the EKATO technology centre in Schopfheim, Germany, on scales of 50 litres and 1 000 litres. Different types of impellers which were an option for the applied process conditions were tested and their performance compared. The results showed that the ISOJET-B impeller (Figure 2) design yielded the best performance at BIOX® reactor conditions. Scale-up with the ISOJET-B was done in order to apply it in the 21 m³ live volume test reactor at Fairview mine in South Africa. At Fairview tests were performed using model systems and eventually under real plant conditions with BIOX® slurries.

Mixing: characterization of the BIOX® process

The basic mixing tasks encountered in practice can be classified into four main categories:

- **Blending**
  - mixing miscible liquids; eliminating differences in concentration, temperature, etc.
- **Suspension**
  - uniform distribution of solids
  - off-bottom suspension of solids
- **Dispersion gas/liquid and liquid/liquid**
  - mass transfer between the gas/liquid phases and liquid/liquid phases
  - stable emulsions
- **Heat transfer**

Every mixing task is governed by natural laws, which must be known for the scientific design of the agitator. Complex mixing tasks involve two or more of these mixing tasks simultaneously. In these cases, special attention must be given to the dominant mixing category. (Figure 3.)
For the continuous BIOX® process all of these mixing tasks have to be fulfilled. Homogeneous process conditions, i.e. of oxygen, pH, temperature, nutrients, are very important to be able to establish and keep a stable bacterial population. All of these parameters are related to blending. High pumping rates and therefore short mixing times will ensure a high degree of homogeneity.
Since ore slurries are processed solids, these have to be suspended. A high degree of homogeneity for all particle sizes has to be achieved to prevent an accumulation of particles with time. The physical properties of the treated solids and the pure liquid have to be taken into account when designing the agitator. These properties will affect the hindered settling velocity of the particles which release a settling power. In order to maintain a defined degree of uniformity the agitator must provide a power input to the liquid to counteract this settling power.

Air has to be dispersed so that enough surface is created between the air and the slurry. This will ensure that enough oxygen is transferred to the bacteria. The specific power input by agitation is one of the main parameters to ensure high mass transfer rates. Therefore it is necessary to have sufficient knowledge of the power number \( Ne \) of an impeller at gassed conditions. With gas being added to an impeller the friction between the impeller and the fluid will be reduced, so that the ungassed power number \( Ne_0 \) is greatly diminished, as shown in Figure 4. The amount of gas being added to an impeller is described by the dimensionless gassing number \( Q \),

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Q = \frac{q}{n \cdot d_2^3}
\]

where \( q \) is the gas feed rate, \( n \) the shaft speed and \( d_2 \) the impeller diameter.

Besides the air dispersion duty of the impeller it has to be confirmed that the impeller will not flood, meaning running completely in a gas cavity.

The oxidation of sulphide minerals is an exothermic process and the reactors must be cooled continuously, meaning heat transfer is of importance as well. Cooling is done by circulating cold water through a series of cooling coils installed inside the reactors.

Using the experience of an agitator manufacturer, the required power inputs to solve the separate mixing tasks can be evaluated. Calculations showed that the gas/liquid dispersion duty requires the highest level of power input and therefore is the dominant mixing task.

![Figure 4. Reduced power input due to gassing](image-url)
Test work

EKATO laboratory

As described earlier, the gas dispersion duty is the main mixing task and therefore the decisive design parameter. Therefore tests were mainly focused on the gas dispersion duty. Since the power input is of utmost importance, power number measurements have been done for different impeller types and gassing conditions.

Measurements at the EKATO laboratory were carried out at two different test scales, 50 litres (Figure 5) and 1 000 litres. Air was, as in the production scale the BIOX® reactors, added via a sparge ring located below the impeller. Tests were run at different gas feed rates and shaft speeds and the torque measured. From the torque measurements the power number could be derived. Figure 6 shows the comparison of two impeller types for BIOX® conditions.

Figure 5. Test set-up 50 litres

Figure 6. Bioleaching—power input due to gassing
As can be seen, the power did not drop at the very low $Q$ numbers as described before but increased. Two curves for different impeller types are given. This increase of the power number is a known characteristic of impellers at very low gassing rates, although so far no explanation can be found in literature. Anyhow, this increase in power number has to be known and considered to properly design the agitator. By choosing the appropriate test conditions in the 50 litre and 1000 litre scale a wide set of dimensionless data was obtained. This enables the design of the agitator for a required gassed power input for any production scale and therefore to fulfil the mass transfer mixing task.

To compare different impeller types regarding their suspending performance, model particles were added to the test vessel while measuring the gassed power numbers. This allowed EKATO to compare different impeller types easily. Not surprisingly when tested, the radial flow types of impellers showed a poor solids suspension performance. Although these types of impellers in general are able to handle more gas than axial flow types, this disqualifies them for the BIOX® process. The EKATO ISOJET-B impeller showed the best suspending performance at gassed conditions.

To compare the mass transfer performance of the different tested impeller types, a model reaction was applied at the 50 l scale. At comparable test conditions, i.e. the agitator power input, all impeller set-ups showed more or less the same mass transfer capability.

All tests at the EKATO lab so far were carried out using model systems. To get additional information how the different impeller types perform in original slurry, a 50 l BIOX® sample was shipped from the Fairview mine site to EKATO. Slurry samples were taken from the vessel bottom and liquid surface and the particle concentrations compared. The ISOJET-B showed a very homogeneous distribution of the solids over the filling height; no differences in solids contents were measurable. The main advantage of the ISOJET-B was its fast resuspending capability for complete settled out conditions (after 16 h), see Figure 7.

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Figure 7. Testing with original slurry—restart after 16 h
**Fairview test reactor**

After the successful tests with the ISOJET-B at the EKATO technology centre a test reactor of 21 m³ live volume was installed at the Fairview BIOX® plant in South Africa. The test reactor is shown in Figure 8. A scale-up for the ISOJET-B was done using the data derived from model testing. An impeller with a diameter of 1 250 mm was machined and sent to the mine site. Again model tests were performed before finally testing the impeller at real BIOX® conditions.

First the power number was measured for different gassing rates in water. Test results from the EKATO laboratory could be confirmed. After these tests mass transfer measurements were carried out to be able to predict the mass transfer performance for bigger production reactors. After these tests with model liquids, the ISOJET-B was tested at real plant conditions. Ore slurry was added from the production plant and the same data derived/analysed as for the production-scale reactors.

- **Mass transfer/chemical results**—continuous testing over several weeks was carried out. Achieved oxidation rates and process specific parameters such as pH, dissolved oxygen, Fe²⁺ to Fe³⁺ conversion values, OUR etc., were measured during a daily routine sampling procedure. All measured data were within specifications and constant. The average amount of oxidized sulphur was higher than achieved in the adjacent production plant.
- **Solids suspension**—Two litre slurry samples were taken at four sample nozzles at different filling heights. Solids’ homogeneity over the filling height was excellent. No difference in solids concentration from vessel bottom to filling level was observed.

**Summary and conclusions**

Extensive water testing and continuous slurry testing was performed at lab and pilot scale. Based on the favorable results generated from these test, the EKATO ISOJET-B impeller was classified as suitable impeller to be used in commercial BIOX® installations. Additional...
information on the mixing characteristics in this specific process could be derived and helped to even better understand the process. Design values were confirmed by testing, and will be applied to design the production scale reactors for upcoming projects. General design parameters were agreed upon between BIOMIN and EKATO.

This successful joint development shows the importance of close cooperation between technology licensors or end-users and equipment suppliers. It is vital for understanding all the factors influencing the mixing performance of processes. Exercises such as this will provide equipment suppliers and plant operators more with confidence in managing further scale-ups at ever larger engineered plants.

Wolfgang Keller
Senior Process Engineer, EKATO RMT GmbH, Schopfheim, Germany

Education:
MSc Process Engineering University of Karlsruhe, Germany.
Professional Memberships: VDI

Current position:
Senior Process Engineer working for EKATO Mixing Technology since 9 years.

Previous affiliations:
Assistant production manager and research and development at LONZA, Germany.

Experience:
• polymer plant operation
• engineering / construction
• process development
• R&D mixing technology
• EKATO expert for minerals processing.