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Mycrobially induced processing of mineral fines

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ABSTRACT

Microorganisms such as Bacillus polymyxa which occur indigenously associated with several ore deposits, bring about significant surface chemical changes on interacted minerals such as hematite, corundum, calcite, quartz and kaolinite. Bacterial interaction rendered quartz and kaolinite surfaces hydrophobic, while hematite, corundum and calcite surfaces became more hydrophilic. Biotreatment of mineral mixtures containing the above minerals was found to result in selective flocculation and selective flotation. It is shown that selective removal of silica and alumina from iron ores and bauxite can be brought about by biological processes. Mechanisms behind such microbially induced beneficiation processes are illustrated with respect to processing of fine particles.

Key Words : *Bacillus polymyxa, Mineral fines, Iron ore, Flocculation, Surface chemistry*

INTRODUCTION

Although the use of microorganisms in ore leaching is well established, their application in mineral beneficiation is not adequately understood. Different from bioleaching, biobeneficiation, by definition, refers to selective removal of undesirable mineral constituents from an ore through interactions with microorganisms, thus enriching it with respect to the desired valuable minerals. Various types of autotrophic and heterotrophic bacteria as well as fungi are known to interact with sulphide and oxide minerals in such a fashion so as to remove selectively one or more mineral constituents in an ore body. As a result, innovations in biotechnology have recently paved the way for development of alternative mineral beneficiation techniques.

Microbe-mineral interactions yield results that are of relevance to various applications:

1. Adhesion of microorganisms to mineral substrates resulting in biofilm formation,
2. Biocatalysed oxidation, reduction, conplexation and precipitation reactions, and
3. Reactions of bacterial cells and metabolic products with different mineral constituents in an ore matrix.

The end result of such biological processes is formation and conversion of various mineral forms, surface modification, selective dissolution of mineral constituents and bioaccumulation of dissolved metal ions. Mineral surface hydrophobicity itself can be brought about by controlled microbe-mineral interactions. Metabolic products as well as the bacterial cell components including the cell wall and membrane can take part in these mineralogical reactions.

It is well established from our previous study that either B. polymyxa or its metabolite renders the hematite and corundum surface hydrophilic[1-5]. However, similar interactions make quartz surface hydrophobic. The above difference in surface properties has been utilized to efficiently separate quartz from hematite and alumina.

The role of microorganisms in increasing surface chemical changes on minerals is examined in this paper with respect to flotation and flocculation phenomena. The manner in which valuable minerals from fines can be separated through bacterial interaction is illustrated. Mechanisms in microbe-mineral interactions with respect to flocculation of fine particles and surface hydrophobicity are discussed.

MATERIALS AND METHODS

Bacterial Strain and Growth Conditions

A pure strain of *Bacillus polymyxa* NCIM 2539 was used in all the studies. A 10% v/v of an active inoculum was added to the medium and incubated at 30oC on a rotary shaker at 240 rpm. The bacterial growth pattern was studied by microscopic counting using a Petroff-Hausser counter under a phase contrast microscope and also by colony counting after plating. pH changes during bacterial growth was monitored and enough cell mass generated by continuous growth for 8 hours. The culture was filtered through filter paper (Whatman No. 1) and centrifuged at 27,000 g for 15 minutes. The cell pellet was washed several times and resuspended in distilled water.

In some tests, the bacterial strain was adapted to corundum by repeated subculturing upto 6 months in the Bromfield medium in the presence of

5% (w/v) mineral. These adapted strains were used in some beneficiation tests and their performance compared with unadapted strains.

A batch culture after growth in the medium was centrifuged at 31,000 x g for 20 min. to separate cells from the extracellular materials, followed by filtration of the supernatant through sterile filter membrane (Millipore, 0.45 ..m pore size, the membrane made of surfactant-free cellulose nitrate and cellulose acetate). Bacterial proteins present in the cell free metabolite solution were precipitated by slow addition of ammonium sulphate to a saturation level of 65%. The precipitate was separated and the supernatant desalted for determination of its polysaccharide concentration. The proteinaceous precipitate was redissolved in minimum volume of 0.02 M Tris-hydrochloride buffer at pH 7 and dialized against the same buffer over 18 h. The precipitate formed during dialysis was removed by centrifugation and discarded. The supernatant was used for protein estimation.

Minerals

Han-picked pure mineral samples of hematite, corundum, calcite, kaolinite and quartz used in this study were obtained from Almirock Indscer Fabriks, Bangalore, India. The samples were subjected to dry grinding in a porcelain mill. Th ground sample was then subjected to dry screened and the < 38 μm size fraction was used in adsorption, flocculation and electrokinetic studies. A (75-110 μm) size fraction was used in flotation tests.

In some cases, actual iron ore samples were used in flotation and flocculation tests.

Electrokinetic Measurements

Electrophoretic measurements were made using Zeta-meter 3.0. Mineral samples before and after interaction with bacterial cells and metabolite were dispersed in 10-3 M KNO_3 solution for the purpose. Zeta potentials as a function of pH were determined for different minerals before and after interaction.

Adsorption Studies

Adsorption of bacterial cells, proteins and exopolysaccharides onto different minerals was estimated at different pH values and concentrations. A 10^{-3} M KNO_3 solution was used as the base electrolyte for the purpose. In all adsorption tests, the time of equilibrium was fixed at 15 minutes. After interaction, the residual reagent concentration in the supernatant was estimated.

Flotation Tests

One gram of the mineral sample was used for the flotation of the minerals to study the influence of bacterial pretreatment.

The mineral sample was taken in 200 ml deionised double distilled water and the pH was adjusted to the desired value[7-9]. The conditioning period was 5 minutes and the flotation was carried out for 5 minutes under a nitrogen flow rate of 40 ml/minute using a Hallimond tube.

Flotation tests using actual iron ore samples were carried out using a Leaf and Knoll cell at 2.5% pulp density. Flotation tests with pure minerals and the iron ore samples were carried out under different conditions as detailed elsewhere to establish the influence of prior biotreatment. In some tests, an isododecyl oxypropyl amino propyl amine was also used as a collector reagent.

Settling and Flotation Tests

To study the settling rates of the different minerals, 5 g of each sample were dispersed in 100ml of deionised double distilled water in a graduated cylinder. The weight settled as a function of time and pH was monitored in the presence and absence of the bacteria or metabolite.

For selective flocculation studies, artificial binary and ternary mixtures of the minerals in equal proportions were placed in a 100 ml graduated cylinder and diluted with make-up water to near the 100 ml mark so that the subsequent addition of bioreagents would give a total pulp volume of 100 ml. At this point, the pH of the pulp was adjusted either with sodium hydroxide or nitric acid which was followed by the addition of reagents in three equal portions, mixing being performed between each addition by gently inverting the cylinder three times between each addition. After the final addition, the cylinder was inverted five times and set down. The settling of the mineral particles in the mixture began immediately. After one minute, the mud line had reached the bottom. 90 ml of the supernatant was decanted out. Another 90 ml of water, whose pH had been predjusted to the same value was added to the remaining solids. The cylinder was inverted five times, set down and the settling and decantation procedure repeated. The desliming process was performed six times. The sink and float fractions were analysed each time. Control experiments in the absence of bioreagents were also carried out under similar conditions for comparison purposes.

RESULTS AND DISCUSSION

Selective Flotation and Flocculation of Minerals Through Bacterial interaction

Bacteria such as *Bacillus polymyxa* and their metabolic products, mainly, exopolysaccharides and bioproteins interact effectively with oxide and sulphide minerals and bring about significant surface chemical changes. Detailed electro-

kinetic studies have shown that interaction of the above bacteria with quartz, hematite, calcite, kaolinite and corundum bring about shifts in isoelectric points. Shifts in isoelectric points for various minerals after interaction with cells of *Bacillus polymyxa* and their metabolites are illustrated in Table 1.

Table 1 : Shifts in isoelectric points with various minerals

Mineral	pH corresponding to IEP	
	Before interaction	After interaction
Quartz	1.7-1.8	3.6-3.8
Kaolinite	1.8-2.0	2.5-3.0
Corundum	7.0-7.2	2.0-4.0
Hematite	5.8-6.0	2.0-4.0

Such significant shifts in the isoelectric points of various minerals are indicative of chemical interaction. Bacterial cells adsorb on the mineral surfaces to different degrees of coverage and along with metabolic products form a biofilm. The adsorption tendency of the bacterial cells follow the sequence:

Kaolinite > Calcite ≥ Corudum ≥ Hematite > Quartz

Such an adsorption was also found to be almost independent of pH between 2 to 10 indicating non-electrostatic forces being responsible for bacterial mineral adhesion.

Major consequences of bacterial interaction and adhesion of relevance to mineral beneficiation are the following:

(a) Changes in surface chemistry

(b) Surface modification (hydrophobicity or hydrophilicity)

(c) Selective dissolution

The above surface chemical changes could be seen in the light of flocculation and flotation of mineral particles before and after interaction.

Variation of contact angles for some minerals before and after interaction with bacterial cells is illustrated in Table 2.

Table 2 : Variation of contact angle before and after bacterial interaction

Mineral	Before interaction	After interaction
Quartz	50	60
Hematite	40	No bubble contact
Corundum	42	No bubble contact

As could be seen, quartz surfaces are rendered more hyrophobic after bacterial interaction while hematite and corundum become more hydrophilic. Similar tests indicated that kaolinite behaves similar to quartz while calcite surfaces are rendered more hydrophilic after bacterial interaction.

Flotability of various minerals before and after bacterial interaction is illustrated in Table 3.

Table 3 : Flotability of minerals before and after bacterial interaction

Mineral	Percent flotation	
	Before interaction	After interaction
Quartz	4	60-80
Kaolinite	38	80-90
Corundum	5	2-10
Hematite	4	2-4
Calcite	8	7-8

Flotability of quartz and kaolinite is promoted by bacterial interaction. On the other hand, bacterial interaction does not promote the flotability of corundum, hematite and calcite.

Even though quartz and kaolinite can be floated after bacterial interaction even in the absence of any flotation reagents, addition of trace amounts of appropriate collector reagents further promote their flotation. Efficient silica removal from iron oxides, alumina and limestone can be achieved trough flotation through bacterial pretreatment. Flotation tests with 1:1 mixtures of hematite-quartz, alumina-quartz and calcite-quartz after biotreatment for 5 minutes in the presence of bacterial cells indicated that more than 95% of silica could be removed.

Settling rates of various minerals corresponding to one minute of interaction (-400 mesh) at different pH values in the presence of bacterial cells and bacterial metabolite are illustrated in Table 4. While the settling rates of hematite, calcite and corundum particles were increased after interaction with either bacterial cells or the metabolite, those of quartz and kaolinite were seen to be significantly decreased after similar treatment. Flocculation of calcite, hematite and corundum and dispersion quartz and kaolinite is facilitated by bacterial interaction. Various polysaccharides such as starches and dextrans are used as depressants for iron oxides in iron ore flotation. Selective flocculation of iron oxide with dispersion of silica can be achieved by addition of the above polysaccharides. Biopolymers

such as those containing exopolysaccharides can interlink the mineral particles through polymer bridging and flocculate the mineral fines selectively. Increased affinity of bacterial cells and exerted polysaccharides towards hematite and corundum bring about their selective flocculation facilitating their rapid settling in an aqueous medium.

Table 4 : Settling rates of various minerals interacted with cells and metabolite for 5 minutes at 5% pulp density (-400 mesh)

Mineral	pH	Percentage weight settled in one minute		
		Control	Bacterial cells	Metabolite
Quartz	4-5	58	10	17.1
	7	45	18	-
	12	38	11	-
Kaolinite	4-5	85	40	16.5
	7	70	20	-
	12	62	18	-
Corundum	4-5	85	97	90
	7	82	96	-
	12	70	90	-
Hematite	4-5	84	99	92
	7	80	95	-
	12	70	98.8	-
Calcite	7	45	90.0	93
	12	50	91.0	-

Results of selective flocculation tests carried out with mineral mixtures substantiate the above conclusion. Typical results of selective flocculation on 1:1 mineral mixtures are presented in Table 5. It could be readily seen that it is possible to separate efficiently silica and silicates from alumina, calcite and iron oxide through bioflocculation. However, it is not possible to separate alumina from hematite efficiently using ordinary bacterial cells since bacterial interaction brings about similar surface chemical changes on both of them. Tests with hematite-corundum mixtures have shown that both the minerals settled down faster in an aqueous medium after bacterial interaction without any selectivity. However, it has been observed that through the use of corundum-adapted strains of *B. polymyxa*, efficient separation of alumina from iron oxides can be achieved. Typical selective flocculation results are shown in Table 6. At pH 7.0 more than

99% separation could be obtained between hematite and corundum. Unlike the case with unadapted cells, corundum particles could be effectively settled (flocculated) with the selective flocculation of only corundum using the corundum-adapted strain (hematite dispersed). It has been found essential to maintain such preadapted strains in the presence of corundum mineral in the medium in order to preserve this acquired property of the organism. Subculturing of the adapted strain in Bromfield medium in the absence of added corundum leads to loss of this acquired adapted property.

Table 5 : Selective flocculation of mineral mixtures (1:1) to separate silica (-400 mesh)

Mineral combination	Conditions	No. of desliming	Separation efficiency %
Corundum-Quartz	pH 7, 6x109 cells/ml 5 min	1	89.3
		2	92.6
		3	96.1
		4	98.9
		5	99.6
Hematite-Quartz	pH 7, $6x10^9$ cells/ml 5 min	1	20.8
		2	51.6
		3	67.3
		4	92.3
		5	95.5
Hematite-Kaolinite	pH 9, $6x10^9$ cells/ml 5 min	1	29.18
		2	36.77
		3	41.80
		4	54.50
Calcite-Quartz	pH 7, 6x109 cells/ml 5 min	1	25
		2	38
		3	56
		4	71
		5	89
		6	97.0

As can be seen from the results in Table 5, hematite-kaolinite separation at finer sizes of these minerals (-400 mesh) resulted in about 55% separation efficiency. Since coating of kaolinite onto hematite particles would reduce the separation efficiency. However, at higher size ranges of these minerals (-150+200 mesh), more efficient separation could be brought about through selective flota-

tion. For example, a separation efficiency of about 85% could be obtained through flotation of 1:1 mixtures of hematite and kaolinite after biotreatment with cells of *B. polymyxa*. Similar results were also obtained with a ternary mixture of hematite, kaolinite and quartz, after biotreatment and flotation (85% overall iron recovery with a grade of 62% of Fe).

Table 6 : Separation of corundum-hematite (1:1) mixture selective bioflocculation using corundum adapted cells

Number of desliming	Percent iron removal in sands			
	pH			
	4	7	9	12
1	31.4	50.0	40.3	33.3
2	50.0	58.3	50.0	41.7
3	58.3	66.7	58.3	50.0
4	63.3	75.2	61.7	53.3
5	70.1	83.3	66.7	56.7
6	80.1	99.2	6.7	58.3

The differences in bacterial cell adsorption, nature of interaction products and the resulting alternations in the surface chemical behaviour of the minerals could be taken advantage of in the beneficiation of ores containing the various mineral constituents. The various minerals studied in this work constitute a typical iron ore system. Removal of silica and alumina from iron ores is a major problem facing the iron and steel industries, the world over. Systematic studies carried out with hematite-corundum-quartz and hematite-kaolinite-quartz mixtures after interaction with adapted strains of *B. polymyxa* showed that silica, alumina and alumino-silicates can be effectively removed. The utility of biobeneficiation is further demonstrated with respect to the beneficiation of an iron ore sample for removal of silica, as illustrated in Table 7. The beneficial role of biotreatment in silica removal from iron ore is clearly evident. Desiliconisation can be achieved either by flotation or selective flocculation in the presence of bacteria.

Biologically Induced Flocculation and Flotation - Probable Mechanisms

The interfacial region of the mineral substrate and biofilm is modified by the presence of microorganisms and their metabolic products. Charge separations can occur by dissociation of ionizable groups, such as -OH, -COOH, $-NH_2$ and $-SO_3H$. Thus with oxide mineral such as Fe_2O_3, Al_2O_3 and SiO_2 dissociation of

surface OH can occur and the surface may become positively or negatively charged depending on the pH.

$$\begin{matrix} & & O^+ & & \\ -M-O^+H_2 & \Leftrightarrow & -M-OH & \Leftrightarrow & -MO^- + H_2O \end{matrix}$$

The biofilm will influence the above equilibria and adsorption of biological products can occur. Neutral macromolecules can also be adsorbed on charged or uncharged mineral surfaces. If the surface is charged, then adsorption of a biomolecule can cause a redistribution of the counter ion charge. This would lead to shifts in zeta potentials. Therefore, on any hydrophilic surface, adsorption of exo-polysaccharides (biofilm) can occur by strong hydrogen bonding between amino or carboxyl groups, peptide units or ether bridges as well as other polar groups on biological and mineral surfaces. This will also lead to redistribution of charges in the double layer. The polysaccharides, consisting of several flexible sequences, may adopt different conformations at the mineral-solution interface.

Table 7 : Silica removal from Iron ores through bioflotation and bioflocculation

Experimental conditions	Concentrate		
	%Fe	$\%SiO_2$	%Fe-Recovery
1. Flotation without biotreatment using 0.15 kg/ton of amine collector at pH 9.0 (-200 + 300 mesh)	No silica removal		
2. After bacterial interaction for 5 Min - followed by collector-less Flotation (-200 + 300 mesh)	50	10	90
3. After bacterial treatment as above Followed by flotation in the presence Of 0.15 kg/ton of amine collector (-200 + 300 mesh)	67	0.9	90
4. Selective after biotreatment flocculation of -400 mesh ground iron ore at pH 7.0 with 6 desliming stages in between stages (5 min interaction with 10^9 cells/ml)	61	3	75

Three major types of interparticle interactions can be distinguished, namely double layer, steric and Van der Waals. The first type of interaction occurs between particles with an electrical double layer. Steric interactions occur when particles have adsorbed layers of surfactants, while the third type comprises of dipole-dipole, dipole-induced dipole and dispersion forces.

The chemical composition as well as the physical architecture of the biofilms on mineral surfaces need to consider polysaccharides, proteins, fatty acids as also inorganic materials such as silica, silicates and metal ions such as Fe^{2+}/Fe^{3+}, Al^{3+} and Ca^{2+}.

Flocculation by Biopolymer Bridging

One aspect of flocculation is bio-polymer bridging. Bridging flocculation occurs because segments of a bio-polymeric chain adsorb on different particles, thus linking the particles together. Adsorption of the bio-polymer at the mineral surface is an essential step which involves attachment of many segments. Polymer adsorption is often irreversible and involve electrostatic, hydrophobic, hydrogen-bonding, ionic bonding and dipole-crystal field interactions.

Flocculation of hematite, alumina and calcite can occur through polysaccharides secreted by bacterial metabolism.

One of the most important properties of flocs produced by bio-polymers is that they can be significantly stronger than aggregates formed when particles are destabilized with simple salts. By reducing or eliminating the electrical repulsion between particles causes them to be held together by Van der Waals' forces, which may be rather weak. Polymeric bio-flocculants, (insoluble biofilms) provide many links between particles, the strength of which is dependent on the carbon bonds along the polymeric backbone. Under the circumstances, the adsorption is essentially irreversible. Several polymer bridges between particles would be needed to form flocs that can withstand shear. This can be achieved in practice and large, strong flocs can be produced, with biopolymers of high molecular mass. For very similar reasons, bio-polymer flocculants can cause deposited particles to be attached strongly to the mineral substrates.

Effective bridging flocculation requires that the absorbed biopolymer extends far enough from the particle surface to attach to other particles, and that there is sufficient free surface available for adsorption of segments of these extended chains of the polysaccharide. When excess biopolymer is adsorbed, the particles can become destabilised because of surface saturation or by steric destabilization. At low concentrations there is insufficient biopolymer to provide adequate links between particles, and with larger amounts destabilization may occur.

For bridging flocculation, the adsorbed polymer has to extend far enough from the surface to overcome electrical repulsion forces, implying that at low ionic strength biopolymers of quite high relative molecular mass would be needed. As ionic strength increases, the range of electrical repulsion is reduced, and low relative molecular mass polymers could be very effective.

An optimum charge density of electrolytes for bridging flocculation is fairly well established. Chain expansion can give improved flocculation, whereas reduced adsorption would have the opposite effect and the optimum degree of hydrolysis represents the best compromise between these two tendencies. Very similar results have been reported for flocculation by starches. A limited degree of ionic character (approximately 30%) imparted by phosphate or sulphate groups is found to give optimum flocculation.

Charge Neutralization

The only effective polymeric flocculants are polyelectrolytes with charge opposite to that of the particles. With oppositely charged polyelectrolytes, e.g. exopolymer, it is likely that adsorption occurs, giving a rather flat configuration of the adsorbed chain because of the strong ionic interactions between the ionic groups of the polymer and charged sites of the particle surface. This would probably reduce the possibility of bridging contacts with other particles, especially with polyelectrolytes of low relative molecular mass. However, the adsorption of a cationic polyelectrolyte by a negatively charged particle would reduce the surface charge of the latter and this charge neutralization could be an important factor in destabilization of particles.

It may not be immediately apparent whether bridging or charge separation is an operative mechanism. There is a considerable amount of evidence suggesting that for cationic polyelectrolytes and negative particles, charge neutralization plays a large part in the flocculation processes. The most direct evidence come from measurements of electrophoretic mobility, and therefore from the zeta potential measurements of particles with added polyelectrolyte. With many different types of particles, including clays, cellulose fibers, silica, exopolymers, biofilms, glycans, proteins and bacteria, it has been found that optimum flocculation dosage of cationic polyelectrolyte corresponds quite closely to the amount required to give a new electrophoretic mobility that neutralizes the particle charge.

Although charge neutralization goes some way toward explaining the behaviour of cationic polyelectrolytes, especially polysaccharides, there are some effects of relative molecular mass and ionic strength that do not quite fit this simple picture. These can be better explained by the electrostatic patch model. Essentially these models apply to cases where the particles have a fairly low density of immobile surface charges and the adsorbing polyelectrolytes have a fairly high

charge density. Under these conditions, it is not physically possible for each surface site to neutralize charged segments individually on the polymer chain, even though the particle may have adsorbed sufficient polyelectrolyte to achieve overall neutrality. In this case patches of 'excess positive charge,' corresponding to adsorbed polyelectrolyte chains in a rather flat configuration, surrounded by areas of negative charges, representing the original particle surface could be observed. Particles having these 'patchy' or 'mosaic' types of surface charge distribution may interact in such a way that positive and negative patches come into contact, giving quite strong attachment.

The electrostatic patch concept seems to explain a number of features commonly observed in the flocculation of negative particles with cationic electrolytes. These include a rather small effect of increasing relative molecular mass and the effect of ionic strength on both the breadth of the flocculation dosage range and the rate of flocculation at optimum dosage.

Both the adsorption and flocculation steps are essentially collision processes, the rates of which depend on transport phenomena. Transport mechanisms are diffusion or convection caused by fluid flow, the relative importance of each being determined by the size of particles and biopolymer molecules and the fluid motion. Normally there will be far more biopolymer molecules than other particles, and it might be thought that adsorption would be very rapid compared with the particle collision, and hence flocculation rate. However, it will usually be necessary for a substantial fraction of the added biopolymer to be adsorbed before the particles are adequately destabilized. This applies to both bridging and charge-neutralization mechanisms.

When a biopolymeric flocculant is added to a suspension, several processes are initiated, though the rates at which they significantly affect the flocculation will differ. The steps involved are:

(a) Adsorption of the polymer particles

(b) Rearrangement of adsorbed chains to give an equilibrium configuration (conformational change)

(c) Collisions between particles with adsorbed polymers to form aggregates, so called flocs.

(d) Break - up of flocs

(e) Mixing of the biopolymer molecules among the particles to give a uniform distribution.

These processes are not independent. For instance, if mixing is not achieved very rapidly then an uneven distribution of biopolymer may lead to local over-

dosing and restabilization of some of the particles. In the first case sufficient biopolymer chains need to be adsorbed in order to provide bridges of adequate strength, and in the second the particle charge has to be reduced sufficiently to overcome electrical repulsion.

As evident from the results presented in this work,[6-7] bacterial-proteins do not influence the settling behaviour of corundum, hematite and calcite, while enhancing the dispersion of only quartz and kaolinite. Similarly, bacterial polysaccharides promote flocculation and settling of hematite, calcite and corundum, without significantly influencing the settling behaviour of quartz and kaolinite. The role of biopolysaccharides is similar to that of starch in iron ore beneficiation.

Role of Cell Wall and Metabolites in Mineral Surface Hydrophobicity

The role of bacterial cells and metabolic components such as proteins and polysaccharides in the flotation behaviour of quartz, kaolinite, hematite, corundum and calcite has already been discussed.

Cell-wall protein and metabolically secreted bioproteins induced hydrophobicity on quartz and kaolinite, while polysaccharides confer hydrophilicity on hematite, corundum and calcite. Thus, in a flotation process, bioproteins can aid in the selective separation of quartz and kaolinite from hematite, corundum and calcite. Proteins essentially served as a hydrophobic agent preferentially adsorbing on quartz and kaolinite. Higher surface hydrophobicity and lower surface charge are related to higher dispersion and flotation tendencies. A linear array of hydrophobic amino acids on the cell wall would confer cell surface hydrophobicity. Continuous protein synthesis facilitates the existence of hydrophobicity and maintenance of hydrophobicity. Electrostatic, contact-angle, adsorption and microflotation tests confirm the above mechanism behind biologically induced flotation of minerals. The role of biopolysaccharides could be seen as an essential depressant for hematite, corundum and calcite (similar to starch).

Bacterial adaptation to minerals such as corundum and hematite lead to generation of specific proteins and polysaccharides. Development of such biosurfactants specific to a mineral holds the key to biomolecular recognition. Cell wall and metabolite composition of such adapted cells possesses specific mineral-recognition capabilities. Separation of hematite and alumina through selective flotation or flocculation would thus become possible using "trained" microorganisms.

Bacillus polymyxa and metabolites bring about efficient dissolution of hematite, and calcite through a number of mechanisms such as chelation, acidolysis, reductive dissolution and direct bacterial enzymatic attack[6-7].

CONCLUSIONS

The following major conclusions can be drawn from this work.

Interaction of *Bacillus polymyxa* with minerals such as hematite, calcite, corundum, quartz and kaolinite brings about significant chemical changes. Quartz and kaolinite surfaces were rendered more hydrophobic, while hematite, calcite and corundum, more hydrophilic through bacterial interaction. Such a biotreatment is a very useful in the processing of mineral fines with reference to selective flocculation and flotation. Biopolymers generated through bacterial interaction with the above minerals can interlink fine particles through polymer bridging. Utility of bioprocessing in the beneficiation of iron ores with respect to alumina and silica removal is shown to very promising especially while dealing with ore fines.

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