

Use of Site Blocking Agent for Removal of Silica from Egyptian Iron Ore through Bio-flocculation

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Abstract

This paper is devoted to study the different physico-chemical interrelations of the system iron oxide-quartz in presence of microorganisms. Growing, isolation and selecting of tailored microorganisms to selectively adsorb onto the mineral surfaces of iron oxide or quartz, to be used as the sole flocculating agent or as a surface modifier to enhance the selectivity of the separation process is also one of the main objectives of the present work. The presence of microorganisms enhanced the settling rate of both iron oxide particles but they caused a significant dispersion for the quartz particles. The microorganisms have hydrophobic nature over the entire range of pH (2.0 - 12). The presence of these microorganisms on the surface of minerals changes the zeta potential of mineral surface gradually to reach that of the microorganisms. However, addition of (2.0×10^8 cells) microorganisms as the sole flocculating agent for the binary mixture of iron oxide and quartz in absence of dispersing agent at different pH values yielded products of ~ 94.5 - 97.1 % Fe_2O_3 and 4.37 - 6.4 % silica with recovery of 60.9 - 79.6 %. The best grade (97.1 % Fe_2O_3 and 4.37 % silica) is obtained at the acidic pH of 3.5. The selectivity can be greatly improved in presence of (6×10^{-5} M) SHMP, as a dispersing agent, where a product of better grade (of ~99.2 % Fe_2O_3 and 1.3 % silica) was obtained at the expense of recovery. The grade of the product can also be increased to 99.9 % Fe_2O_3 when the microorganisms was used as a surface modifier during the selective flocculation process while using 6×10^{-5} M SHMP and 80 ppm of PAM at pH range of 3.5 - 5.8. Applying the microorganisms (about 1.0×10^8 cells) for bio-flocculation of an iron ore sample, a product of high grade (95.81 % Fe_2O_3 and only ~ 2.0 % silica with a total recovery of 50.38 %) was obtained from a feed assaying about 55.77 % Fe_2O_3 .

Keywords: Dispersion, selective flocculation, polymers, site blocking agent, surface modifier, microorganisms, iron ore

INTRODUCTION

With the increasing demand for minerals and the continuously diminishing of high-grade ores, the problem of fines becomes important. There are numerous examples of processing systems in which the ore must be deslimed, as the conventional method is inadequate in the subjective range. Treatment of fine particles presents a difficult problem in the chemical industry and raw materials processing, and its solution is required (Abdel-Khalek et al., 2019; Hassan et al., 2017). These fines, which generally range from 1 to 100 μm in size, can be of substantial impact in production, even at low concentrations and additionally can cause potential environmental problems if released to the environment. When selective upgrading of fines is recommended, the process becomes more complicated and difficult (Hassan et al., 2020; Gallios and Matis, 1992). Fines are supposed to be particles with diameters less than one hundred microns, very fines those less than twenty μm while ultrafine are less than five μm . For particles length one μm in size, they are considered as colloidal size range (Sivamohan, 1990). Because of the small mass and large surface area of fines, various problems affect their separation including high reagent consumption, excess froth stability, low adhesion probability, higher dissolution, rapid oxidation, and nonspecific collector adsorption (Somasundaran, 1998).

Processing of fine size ores has resulted in the production of ultrafine particles, which has no response to conventional separation methods. The ultrafine are called slimes, and they are eliminated from circuits followed comminution. Ultrafine are

major losses of valuable minerals which are mined without recovery in processing. Fine particles in a fluid suspension tend to follow the motion of the fluid, rather than move relative to it, under the influence of an external force applied to achieve separation. The formation of large units by selective aggregation is thus a promising way to overcome this hydrodynamic limitation. Once having achieved selective aggregation, the aggregates can be separated from the dispersed material by one of the conventional beneficiation methods. Suspensions can be stabilized and aggregates formed by at least four different mechanisms: including electrolytic coagulation, hydrophobic bonding, magnetic bonding and polymer bridging in which the added flocculants form flocs through the bridging mechanism between the fine particles. The larger size of these flocs, in comparison to the individual particles, enhances their settling and in turns their separation. Higher molecular weight polymers will adsorb on several particles at once, forming a three-dimensional matrix. With bridging polymers, generally, the higher the molecular weight, the better the flocculant (Abdel-Khalek et al., 2020; Yates et al., 2001). Hydrogen bonding is a vital method of adsorption in the case of nonionic polymers as polyacrylamide. The individual bond strength is relatively low, but on acrylamide polymer of molecular weight one million, for example, can form up to 15,000 of these bonds, and the overall bonding force is high. A feature of the hydrogen bond is the short distance between atoms linked by hydrogen, and interacting atoms, which should become close before hydrogen bonding occurrence. There are several hypotheses for the mechanism of formation of the flocs. One possibility, which must certainly play some part in floc formation, is the reduction of zeta potential by the adsorbed charged polymer molecules, allowing the particles to come together by Vander Waals attraction. A second possibility is that the polymer attaches simultaneously, to two particles by its two ends. Further adsorption then occurs, and the polymer molecule is contracted, the particles are down closer together (Wong et al., 1988).

Egyptian iron ore understudy is associated with different gangue minerals. The main gangue minerals are silica. These impurities are finely disseminated in the matrix that needs fine grinding to achieve a considerable degree of liberation (Heikal et al., 2019). The recovery of a valuable mineral from these low grade ores through existed technologies is expensive related to high energy and capital costs (Rostom et al., 2020). It is a challenge to develop a novel efficient and environmentally friendly technique of flotation and waste processing, exploiting the capability of bacteria for selective surface modifications of solids. Several studies have been carried out on the use of microorganisms act as bio-reagents and may induce hydrophobic characteristics once they could adhere selectively on the mineral surface. Physico-chemical properties of microbial cell surface influence their adhesion behaviour. Therefore the Physico-chemical characterization of the microbial cell is essential in order to understand and control the bio-mineral beneficiation process fully. Microbes or microbial fat and secreted metabolites can have specific interactions with minerals. Such interactions of microbes with minerals could be indirect or direct depending on microbial adhesion to particles forming surface modification. Both types of interactions can lead to alteration of mineral hydrophobicity. The two major factors, which contribute to selectivity in bio-flocculation process, are selective adhesion of microbial cells on the mineral surface, which forms a bio-film and causes alteration on the mineral surface, and secondly, selective interaction of attached microbial cells with the added chemicals. Thus, bacterial adhesion plays a critical role in both bio-leaching and bio-beneficiation processes.

Application of bio-reagents as collectors involves several fundamental aspects, surface charge, presence of specific hydrophobic groups and polymers compounds which deeply affect their adhesion to the mineral (Shashikala and Raichur 2002) Therefore, this paper aims at studying the role of bacteria in bio-beneficiation of the iron oxide-silica system in relation to Egyptian iron ore. The role of bacteria on surface characteristics of two single minerals has been investigated using zeta potential, adsorption and bioflocculation.

2. MATERIALS AND METHODS

2.1. Materials

Samples of pure minerals of hematite and quartz were delivered from "Wards" Company, USA. In addition, samples of iron ore are used for selective flocculation experiments. The samples were dry ground in a porcelain mill. The -500 mesh fraction was utilized in adsorption and flocculation studies. Sample purity was investigated by XRD and XRF techniques.

2.2. Size Analysis of Samples

A Laser particle size analyzer "FRITSCH" model "Analyst 22" was employed for size analysis of the pure mineral samples.

2.3. Complete chemical Analysis

Routine chemical analysis of samples was conducted using standard methods. Iron oxide was determined by atomic absorption technique (Ewing, 1975) using "Perkin- Elmer" Atomic Absorption model "A Analyst 200". Silica content was determined gravimetrically. Meanwhile, complete chemical analysis of samples was conducted using "Philips" X-ray fluorescence (XRF).

2.4. X-Ray Diffraction Analysis

Identification of samples composition was studied by computerized XRD. The XRD analyses were carried out using "Philips type 1710 XRD unit" with Ni filter Cu radiation ($K\alpha = 1.5446 \text{ \AA}$) at 40 kv and 20 mA, at scanning speed of one theta degree per minute. The minerals are identified according to ASTM cards No. 05-0490 (D) for SiO_2 , 89-0599 (C) for iron oxide and hematite and 89-0691 (C) for magnetite.

2.5. Adsorption and Flocculation Experiments

One gram of sample, representing either an artificial (binary) mixture of hematite and quartz or that of natural ore, was equilibrated in water after adding the desired quantity of dispersing agent. The pH of the pulp was adjusted at this point to the desired value either with sodium hydroxide or hydrochloric acid. The suspension was conditioned for a definite time before flocculant addition. The flocculant was added dropwise from freshly prepared stock solution (0.1 M), followed by 3 minutes conditioning at high shear and 1 minute at low shear on a magnetic stirrer. The pulp was then transferred to a 100 ml-graduated settling column. The column was inverted five times at 180° and then left to settle for 2 minutes. Both the settled portion and the dispersed fraction were separated, dried, weighed and assayed for iron oxide, phosphorus and silica. All the experiments were carried out at 1% pulp density (Selim et al., 2020).

2.6. Zeta Potential Measurements

A Laser Zetameter "Malvern Instruments" model "Zeta Sizer 2000" was employed for zeta potential measurements. 0.01 gram of ground sample was placed in 50 ml double distilled water with definite dispersant or flocculants concentration at ionic strength of 2×10^{-2} M NaCl. The pH was then adjusted to the required value. The sample was shaken for 30 minutes. Then, equilibrium pH was measured and zeta potential of mineral particles was analyzed (Selim et al., 2020).

2.7. Measuring Selectivity of Microorganisms to Mineral Surface

A Laser particle size analyzer "FRITSCH" model "Analytste 22" was employed for measuring size analysis of single minerals after treatment with microorganisms. A definite volume of each microorganism (10 ml) was conditioned with 1 gram of each mineral during 30 minutes.

2.8. Bacteria Growing and Counting

The microorganisms were grown in liquid medium of 30% mycological agar, 10 g/l sucrose, 1g/l ammonium nitrate and 700 ml double distilled water. The microorganisms incubated at temperature of 25 °C for 2 weeks. Microorganisms' counting was made through turbidity measurements using "Perkin-Elmer" Spectrophotometer "model Lambda 3B". Microorganisms were centrifuged at 15000 rpm and rinsed three times with double distilled water and thereafter diluted in 100 ml double distilled water. Reading of 0.01 at wave length 550 μ m is equivalent to 10^6 cells / ml.

3. RESULTS AND DISCUSSION

3.1. Characterization of raw sample

The XRD patterns of single minerals show the characteristic peaks for iron oxide and quartz minerals with no other associating impurities that confirm their purity. XRD of iron ore sample showed that it is mainly composed of magnetite, quartz and hematite, Figure 1. Magnetite represents the main iron bearing mineral while quartz represent the main associated gangue mineral.

Table 1 shows the chemical analysis of the studied samples. These results illustrate the purity of the single minerals. The Fe_2O_3 in the iron oxide sample is 99.9 % while the silica content in the quartz sample is 99.9 %. Chemical analysis of iron ore sample shows that it contains total Fe 44.24 % (~ 63.26 % Fe_2O_3) and high content of silica (~ 29 % SiO_2) due to the presence of large amounts of quartz as the principal gangue mineral. The Loss on ignition (L.O.I.) is traces (0.63 %) in the sample.

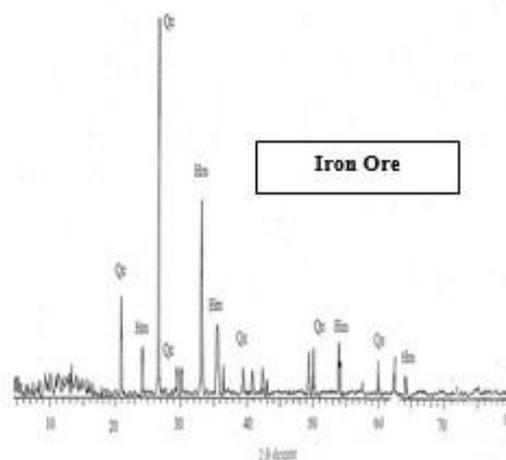


Fig. 1: XRD of natural iron ore sample

Table 1: Chemical analysis of the studied samples

%	Single Mineral		Natural Egyptian Iron Ore
	Iron Oxide	Quartz	
Fe ₂ O ₃ (as total Fe)	99.90	-----	63.26 (44.24)
SiO ₂	0.095	99.90	29
L.O.I.	0.005	0.01	0.63

3.2. Size Analysis of the Studied Samples

The size distribution of the single minerals as shown in Figure 2 have very fine size distribution with 100 % below 1 μm and 5 μm for iron oxide and quartz respectively and d_{50} of 0.4 μm and 2 μm respectively. The samples of natural iron ore was ground to 100 % below 200 mesh (74 μm).

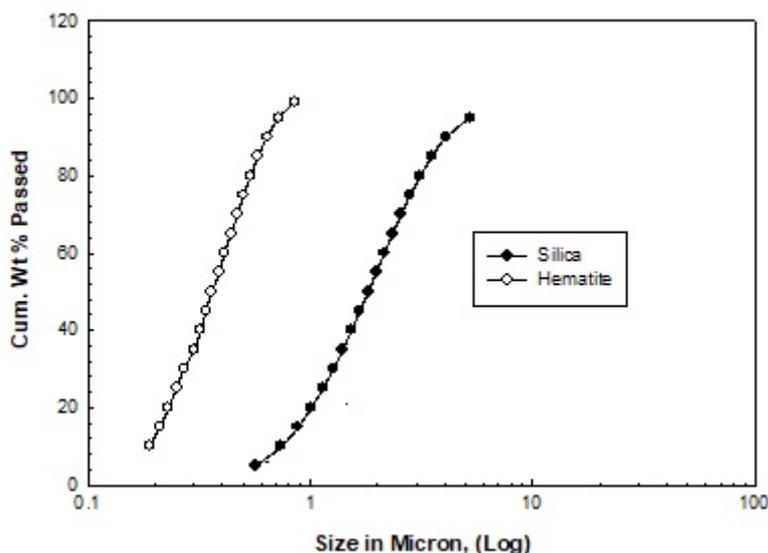


Fig. 2: Size distribution of single minerals

3.3. Effect of Changing pH on Zeta Potential of Single Minerals

The zeta potential of hematite and quartz was determined at two different ionic strength of NaCl over a wide range of pH, the results of which are shown in Figures 3 and 4, respectively. These results indicated that NaCl acts as indifferent electrolyte for hematite and quartz. Generally, the value and sign of zeta potential depend upon the pH of the medium, indicating that both H⁺ and OH⁻ are potential determining ions for each mineral. The sign of zeta potential changes from positive to negative with changing pH of the medium from the acidic to the alkaline range. The results, also, showed that the electronegativity of zeta potential increases gradually with increasing the pH. It can, also, be noticed that the zeta potential increases in magnitude with decreasing ionic strength of counter ions (NaCl), due to the increase in thickness of the diffuse layer, as a result of coulombic interactions which is a dominant role in adsorption process (Selim, 2006; Selim et al., 2020). The zeta potential can be changed, however, by changing the pH or using dispersing agents.

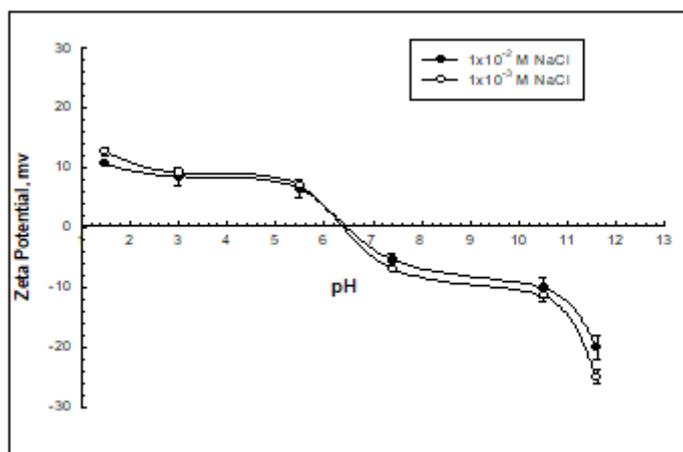


Fig. 3: Zeta potential of Iron oxide

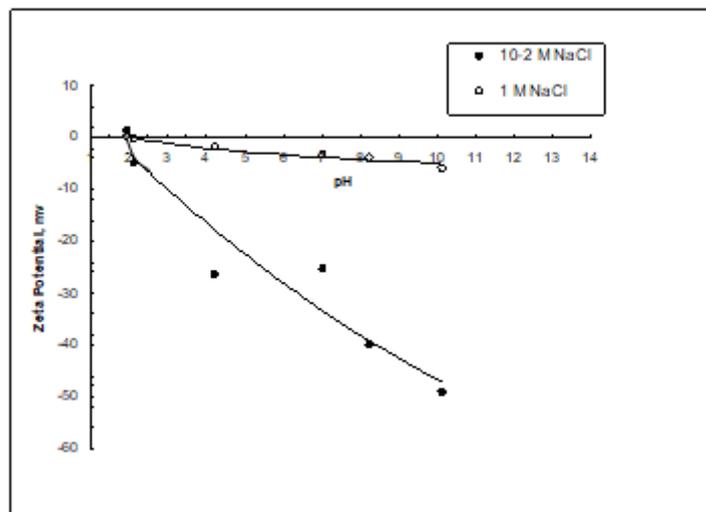


Fig. 4: Zeta potential of silica

For each of hematite and quartz, the results clearly indicate that the two curves, conducted at two different ionic strength of electrolyte, intersect other at pH ~ 6.3 for hematite and at pH 2.0 for quartz. These values are considered as isoelectric point (iep) for hematite and quartz respectively. The recorded values for iep are in concordance with that mentioned by other authors. For example, Dobias (1984) found that iep of hematite can be varied between 5.4 and 8.7 and a value 1.8 - 2.5 was correlated to the iep for quartz (Abdel-Rahman, 1996) whereas a value between 3.0 and 8.0 was correlated for the iep of apatite (El-Mahdy, 2004). Also, it has been shown that the value of the iep of a certain mineral can be affected by many parameters such as the method of determination, history of sample preparation, composition and purity of the mineral (Selim 2006).

3.4. Selective Flocculation of Iron Oxide and Quartz in Binary Mixture

Since iron oxide particles have higher density in comparison to quartz, it is expected that in a mixture containing both minerals, that simulates most of the mineralogical composition of iron ores; PAM can be used as a selective flocculant for hematite while leaving quartz dispersed in the pulp. Such iron oxide-silica system is favourable system for flocculation with PAM to occur for the following reasons:

- The silica forms a more stable dispersion than the hematite which slowly coagulating.
- Silica and hematite are negatively charged in water so hetero-coagulation would not occur.
- The aggregates of iron oxide will settle fast due to their high density.
- Anionic flocculants, such as PAM, are available that will adsorb on iron oxide particles and cause flocs to be formed but not adsorb on the silica particles.

The technique of selective flocculation has been tested to separate a mixture consisting of ~ 89.5 % Fe_2O_3 and 10.5 % SiO_2 . The experiments were performed using 6×10^{-4} M SHMP as a dispersing agent and polyacrylamide (PAM) as a flocculant for iron oxide. The effect of changing the concentration of PAM on flocculation of hematite from its mixture with silica is displayed in Table 2. It can be noticed that with increasing the polymer concentration from 20 - 80 mg/l, the grade is gradually improved, where Fe_2O_3 is increased to ~94.7 % and its silica content is decreased to 5.7 %, at the expense of recovery. The dispersed fractions showed to be contaminated with silica (17.2 - 25.1 %) in comparison to the feed sample. The higher polymer concentration can result in increasing the repulsive forces between the negatively charged adsorbed polymer molecules in addition to the probable role of polymer conformation that might occur at higher polymer concentration. It has been reported that polyacrylamides adsorb strongly on iron oxide through chemical bonding with surface iron atoms and adsorb weakly on quartz because of electrostatic repulsion (Selim, 2006).

Table 2: Selective flocculation of iron oxide - quartz mixture

PAM added, ppm	Flocculated Fraction		
	Fe_2O_3 %	SiO_2 %	% Fe_2O_3 Recovery
20	90.30	9.50	90.96
40	93.13	6.5	83.20
80	94.67	5.70	69.77
Feed	89.50	10.50	

The results in Table 2 show also that the highest grade that be achieved was ~ 94.7 % Fe_2O_3 with ~ 5.7 % silica. Further improvement for such grade through optimizing the different operating conditions did not yield encouraged results. One of the reasons that hinder the selectivity of the selective flocculation process in such fine size range is related to the presence of hetero-

flocculation from the fine particles of quartz together with those of the iron oxide. In a trail to overcome such hetero-flocculation, the concept of site blocking agent (SBA) has been developed. This concept has been examined successively to improve the selectivity of flocculation for apatite-dolomite system to upgrade Florida phosphate ores (Moudgil et al., 1998 and Selim, 2006). However, such new concept of SBA does not tested before for the iron oxide-quartz system to upgrade the quality of iron ores. For this reason, the amenability of introducing concept of site blocking agent (SBA) to improve the selectivity of the iron oxide-quartz system to upgrade the quality of iron ores was studied.

3.5. Application of Surface Modifier for Enhancing Selectivity of Separation in the Iron Oxide-Quartz System

Table 3 depicts the effect of using the surface modifier, as a site blocking agent (SBA) for quartz, under different operating conditions, in the iron oxide-quartz mixture. Selective flocculation in presence of SBA (exp. number 2-4) illustrates clearly the advantage of using SBA as a surface modifier to improve the selectivity of the process. Addition of only 40 mg/l of the surface modifier (Exp. # 2) under, more or less, the same operating conditions yielded a concentrate of higher grade, The Fe_2O_3 % is increased to ~ 97.4 % with silica content of 2.8 % but at the expense of recovery (~ 33 %). Further improvement in the grade can be noticed in presence of higher dosage (6×10^{-4} M) of SHMP and SBA (60 mg/L) where the Fe_2O_3 % is increased to ~ 99.5 % with a significant reduction in the silica content to 0.6 % with a recovery of ~ 47 %. However, the best grade in terms of the highest Fe_2O_3 (99.9 %) and minimum silica (~ 0.3 %) can be obtained by increasing the concentration of SBA to 60 mg/l at pH 5.0. It is clear, from these results, that the adverse effect of hetero-flocculation, which might be responsible for lowering the selectivity of the separation process, can be greatly minimized by applying a suitable surface modifier prior the addition of the flocculant. Adsorption of the surface modifier on silica may act as a site blocking agent (SBA) for some of its sites that help in preventing the higher molecular weight (PAM) flocculant from its adsorption on these adsorption sites.

Table 3: Selective flocculation of iron oxide-quartz mixture in Presence of SBA

#	Conditions	Flocculated Fraction		
		Fe_2O_3 %	SiO_2 %	% Fe_2O_3 Recovery
1	6.0×10^{-4} M SHMP, No SBA 80 ppm PAM, pH 3.8	94.67	5.70	69.77
2	6×10^{-5} M SHMP, 40 ppm SBA 80 ppm PAM, pH 3.8	97.42	2.80	32.70
3	6×10^{-4} M SHMP, 60 ppm SBA 80 ppm PAM, pH 3.8	99.53	0.6	46.96
4	6×10^{-5} M SHMP, 60 ppm SBA 80 ppm PAM, pH 5	99.90	0.3	26.96
	Feed	89.50	10.50	

3.6. Adaptation of Microorganisms for Selective Adsorption on Mineral Surface

Numerous types of microorganisms are grown and isolated from the Egyptian iron (Abdel-Khalek and Farrah, 2004; Abdel-Khalek et al., 2017). Microorganisms of Pseudomonas family was used in this work.

3.7. Selection of Microorganisms as Surface Modifier or as a Flocculant

The change in size distribution of single mineral samples of iron oxide or quartz, after its treatment with each type of the microorganisms was taken as a measure for the selectivity for adsorption. Successful adsorption of such microorganisms will cause, therefore, a degree of aggregation (or dispersion) for mineral particles leading to a change in their size distribution. The larger the change in size distribution, the more selective the microorganism to the mineral surface. The change in size distribution of each single mineral of iron oxide and quartz after treatment with microorganisms was recorded, the results of which are depicted in Figures 5 and 6. These results show different degrees of variation in the size distribution of samples after their treatment. Generally, the change in size distribution of samples after treatment showed the following order: Iron Oxide > Quartz.

It is clear that such treatment with microorganisms of Pseudomonas family caused varying degrees of aggregation for iron oxide minerals while leaving the quartz particles more dispersing in the pulp. This microorganism showed, interestingly, the largest degree of aggregation for the iron oxide mineral with a slight degree of dispersion for the quartz particles.

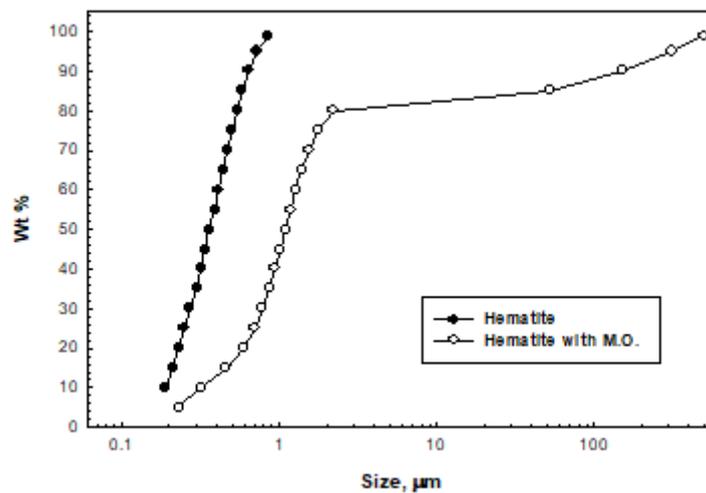


Fig. 5: Size distribution of hematite with M.O.

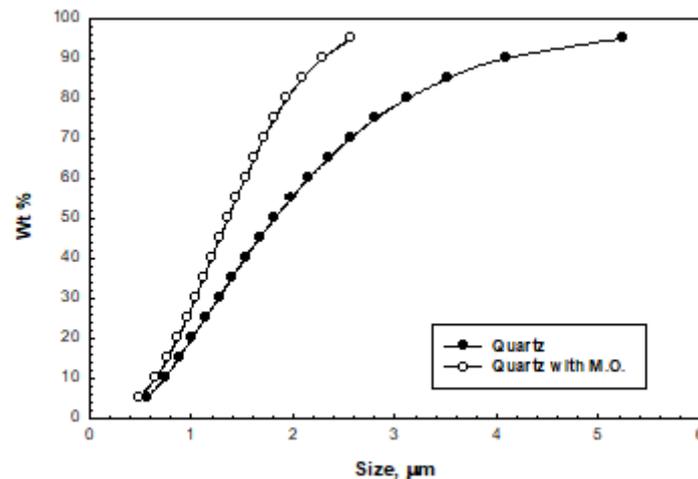


Fig. 6: Size distribution of silica with M.O.

3.8. Characterization of the Selected Microorganism

The selected type of microorganism was subjected for characterization using the routine microbial analysis and counting techniques. Microbial tests, using protein analysis techniques, indicated that this type of microorganism is species of pseudomonas family. Meanwhile, counting results indicated that Pseudomonas family has 2.0×10^7 cell /ml. These values were used in calculating the concentration of microorganisms in the selective flocculation experiments as well as in the adsorption and zeta potential measurements.

3.9. Zeta Potential Measurements for Microorganisms – Single Mineral Systems

The zeta potential measurements of the microorganism alone as well as for each single mineral (iron oxide–quartz) in the absence and presence of microorganism have been conducted. These measurements were performed at constant ionic strength of 2.0×10^{-2} M NaCl. Figure 7 shows the zeta potential of the microorganisms while Figures 8 and 9 illustrate the zeta potential of iron oxide, quartz and apatite respectively. The curve shown in Figure 7 depicts that these microorganisms are, more or less, hydrophobic in nature where their zeta potential values are varied from about -2 to -6 mv only over the entire range of pH (pH 2.0 - 12). In the mean time, the values of the zeta potential, at pH 6.0 – 6.5 in presence of 2.0×10^{-2} M NaCl, for the two minerals were found to be affected by the presence of microorganism. The surface of each mineral becomes less negative with increasing the concentration of the microorganism. This illustrates the effect of the hydrophobic nature of this microorganism of pseudomonas family on the surface of minerals where the zeta potential after adding the MO was found to be decreased gradually to reach that of the microorganism itself.

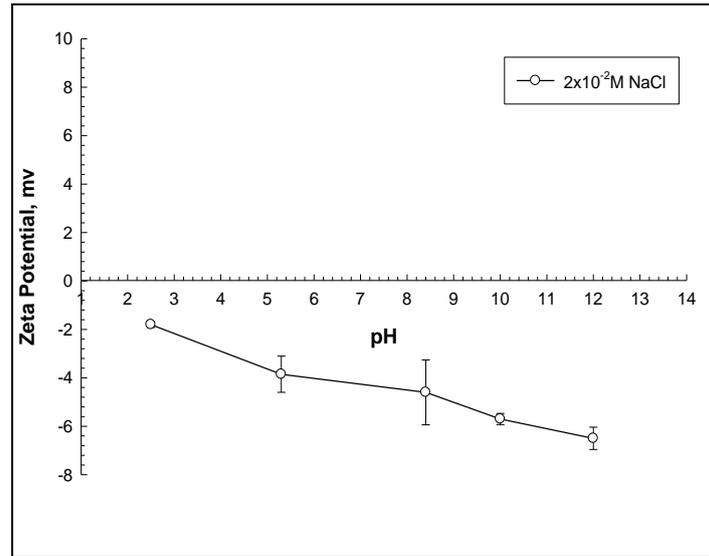


Fig. 7: Zeta potential of microorganism

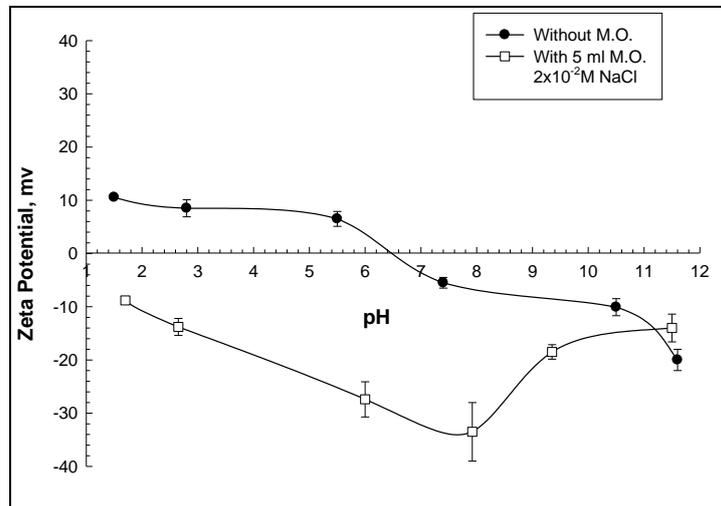


Fig. 8: Zeta potential of hematite in the absence and presence of M.O.

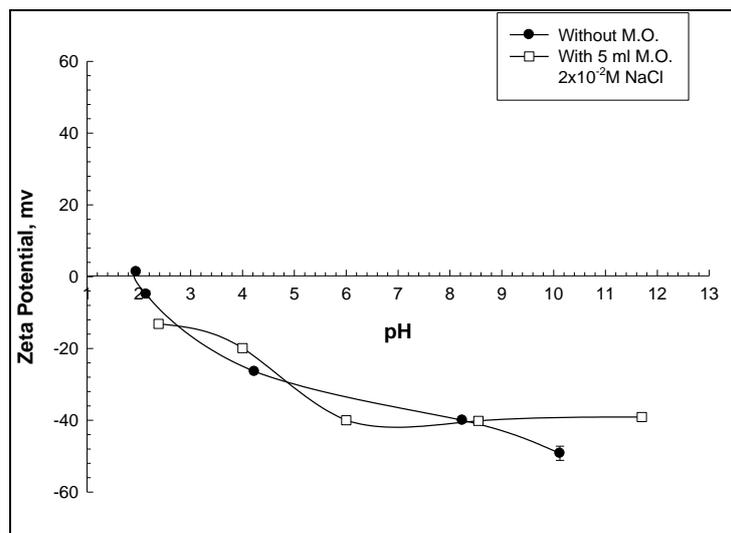


Fig. 9: Zeta potential of quartz in the absence and presence of M.O.

The results of zeta potential of quartz in absence and presence of fixed concentration (1.0×10^8 cells) of *Pseudomonas* microorganism, Figure 9 are slightly changed, whereas the zeta potential values of iron oxide Figure 8 are significantly changed after adding the microorganism. The isoelectric points of iron oxide (pH ~6.3) is disappeared after adding the microorganisms.

The surface of iron oxide becomes more negative in the acidic medium till pH ~ 8.0, after which the zeta potential starts to become less negative to be close from that of the microorganism itself.

3.10. Bio-Flocculation of Binary Mixtures

The amenability of applying the Pseudomonas family microorganisms, to be used as the sole flocculant agent, to selectively separate iron oxide from quartz was tested. Also, applying these microorganisms as a surface modifier for enhancing the selectivity of selective flocculation process, in presence of polyacrylamide as a flocculant, for separating these binary mixtures was also investigated. The experiments were performed at different operating conditions as shown in Table 4.

It is obvious that addition (10 ml of 2.0×10^8 cells) of the Pseudomonas microorganism as the sole flocculating agent in absence of dispersing agent at different pH values can yield products of about 94.5 - 97.1 % Fe_2O_3 and 4.37 - 6.4 % silica with recovery of 60.9 - 79.6 % in comparison to ~ 89.5 % Fe_2O_3 and 10.5 % silica in the feed sample. Under these conditions, the acidic pH of 3.5 gave the best grade (97.1 % Fe_2O_3 and 4.37 % silica) in comparison to the alkaline medium. The selectivity in a weakly acidic (pH 5.6-5.8) or alkaline (at pH 8.5) medium can be greatly improved in presence of (6×10^{-5} M) SHMP, as a dispersing agent, where products of better grade (of ~99.2 % Fe_2O_3 and 1.3 % silica) can be obtained. But this was at the expense of recovery, which was significantly reduced to 28.9 - 31.3 %.

Table 4: Selective Bio-flocculation of iron oxide – quartz mixture

#	Conditions				Flocculated Fraction		
	Micro-organism Conc. (ml)	pH	SHMP (M)	PAM (ppm)	Fe_2O_3 %	SiO_2 %	% Fe_2O_3 Recovery
1	10	3.5	-	-	97.12	4.37	60.87
2	10	3.5	6×10^{-5}	80	99.99	0.1	15.40
3	10	5.78	-	-	94.54	6.43	69.59
4	10	5.6	6×10^{-5}	-	96.20	3.21	31.25
5	10	5.78	6×10^{-5}	80	99.99	0.11	16.14
6	10	8.46	-	-	94.69	6.62	79.60
7	10	8.46	6×10^{-5}	-	99.15	1.32	28.58
	Feed				89.50	10.50	

The results show also that the grade of the product can be significantly increased to 99.99 % Fe_2O_3 in case of using such microorganisms as a surface modifier during the selective flocculation process while using 6×10^{-5} M SHMP and 80 ppm of PAM within the pH range of 3.5 - 5.8. However, the recovery, under these circumstances, was dramatically decreased to 15.4 - 16.1 % only. These results show a very interesting phenomenon where the microorganism can be used either as the sole flocculating agent, for separating one mineral from the others in the sub-sieve size range, or as a surface modifier in combination of polymer. In the latter case the microorganisms help in preventing the hetero-flocculation of fine particles of the gangues with those of the valuable minerals.

3.11. Bio-Flocculation of Fine particles of Natural iron Ore

In these experiments, the microorganism which is species of pseudomonas family is used as the sole flocculating agent for treating a low grade siliceous iron ore from the Eastern desert. This ore is difficult to beneficiate by the conventional separation processes since the silica is finely disseminated in the matrix and in turn, it needs fine grinding to reach to a considerable degree of liberation. The iron ore sample was ground to 100 % below 45 μm whereas the results are shown in Table 5.

Table 5: Selective Bio-flocculation of natural low-grade iron ore

Conditions		Concentrate		
Micro-organism Conc. (cells)	pH	Fe_2O_3 %	SiO_2 %	% Fe_2O_3 Recovery
1.0×10^8	8.0	95.81	2.0	50.38
Feed		55.77	40	

The results depict the effect of using the microorganism as a flocculating agent to separate iron oxide from its associated silica gangue particles in the iron ore sample. Addition of about 1.0×10^8 cells of microorganism at pH 8.0 gave a product of high grade (95.81 % Fe_2O_3 and only ~ 2.0 % silica with a total recovery of 50.38 %) in comparison to about 55.77 % Fe_2O_3 in the feed sample. The minor elements of such concentrate have also been analyzed, Table 6. This grade of concentrate satisfies the requirements for direct reduction application. Such success in applying the microorganisms in selective bio-flocculation process for treating such difficult to beneficiate Egyptian ores might encourage the utilization of such low grade ores to produce value-added products.

Table 6: Minor elements' concentration

Oxides	Concentration, %	Standard, %
MnO	0.02	0.05
CaO	0.15	1.1
MgO	0.019	0.8
TiO ₂	0.027	0.24
P ₂ O ₅	0.05	0.06

CONCLUSION

Two samples representing single minerals of iron oxide and quartz in addition to one sample representing natural iron ore were used for studying the different physicochemical aspects related to both selective flocculation and selective bio-flocculation processes. Zeta potential of each mineral suspensions indicated that the isoelectric points for iron oxide and quartz lie at pH ~ 6.3 and 2.0 respectively.

The technique of selective flocculation has been tested to separate a mixture consisting of ~ 89.5 % Fe₂O₃ and 10.5 % SiO₂. At concentrate with grade, ~94.7 % Fe₂O₃ with silica content of 5.7 % can be obtained using.

Applying the selective flocculation process for a natural iron ore sample in the presence of 60 ppm of SBA (at pH 4 using 6x10⁻⁵ M SHMP and 80 ppm PAM) gave a concentrate assaying ~ 51.8 % Fe and 22.6 % silica with a recovery of ~ 70.1 % in comparison to 42.85 % Fe and 27.66 % silica with a recovery of ~ 92.92 % in the absence of SBA.

The microorganism, which showed the largest change in size distribution, was tested as a flocculant or surface modifier. Such microorganisms are found to represent species of pseudomonas family. The best grade (97.1 % Fe₂O₃ and 4.37 % silica) is obtained at the acidic pH of 3.5. The selectivity can be greatly improved in the presence of (6X10⁻⁵ M) SHMP, as a dispersing agent, where a product of better grade (of ~99.2 % Fe₂O₃ and 1.3 % silica) can be obtained at the expense of recovery. The grade of the product can also be increased to 99.9 % Fe₂O₃ when the microorganisms were used as a surface modifier during the selective flocculation process while using 6X10⁻⁵ M SHMP and 80 ppm of PAM at pH range of 3.5 – 5.8.

Applying the Pseudomonas microorganisms for bio-flocculation of the sample of iron ore, a product of high grade (95.81 % Fe₂O₃ and only ~ 2.0 % silica with a total recovery of 50.38 % was obtained in comparison to about 55.77 % Fe₂O₃ in the feed sample using about 1.0 X 10⁸ cells of microorganisms at pH 8.0.

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