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Iron Minerals Removal from Different Quartz Sands

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Abstract

Quartz sand occurs in varying degrees of purity in dependence on the iron mineral composition, but only a small percentage is suitable for the glass industry after washing and magnetic separation treatment. Bioleaching in combination with washing can increase the quality of quartz sands. The addition of glucose in the leaching medium was important for the continuing leaching activity of iron by heterotrophic bacteria. The amount of bacterial iron removal was not directly proportional to the initial iron content of untreated samples. It was dependent on the mineralogical composition of the quartz sands with kaolinite, illite encapsulated and sealed by goethite (Q1), quartz sands with phengite, kaolinite encapsulated and sealed by siderite (Q2), quartz sands with glauconite encapsulated and sealed by clinoptilolite and Fe smectite (Q3). Heterotrophic bacteria decomposed these sealed polymineral grains with the iron dissolution and caused the formation of a fine-grained fraction of mineral particles predominantly below 49 µm in size. Bioleaching resulted in a 50% decrease in Fe content of Q1, in a 47% decrease in Fe content of Q2 and in a 30% decrease in Fe content of Q3 after 83 days bacterial treatment. This bioleaching pretreatment may be used for the decomposition of iron minerals sealed by silicate minerals and the removal iron surface coatings from different quartz sands. The elutriation process can removed the fine-grained iron particles bioformed after bioleaching. The reductive dissolution of iron polyminerals and washing process may have biotechnological application in the quality improvement of quartz sands.

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1. Introduction

Quartz sands have variable degrees of purity due to a variable mineral composition. Generally, they contain iron minerals, such as iron amorphous oxyhydroxides, goethite, hematite, siderite, tourmaline, garnet (almandine), amphibole, mica, clay and pyrite.

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The dissolution of iron minerals using chemical methods has long been examined because the removal of iron to obtain a significant purity of quartz is considered possible (Du et al., 2011; Tuncuk and Akcil, 2014; Zhang et al., 2012). These chemical methods are usually suitable for achieving a high degree of iron removal but they are expensive, have complex operating conditions, and are environmentally hazardous. That is why it should be used only for the treatment of high grade iron removal from quartz sands with an amount of Fe₂O₃ below 400 ppm according to request of industry or it should be used in the combination with physical and biological methods to reduce cost.

Heterotrophic bacteria have the potential for producing acidic metabolites that can solubilize oxide, silicate, carbonate and hydroxide minerals by reduction, acid attack and complexation mechanisms. Carbonates and silicates contain no energy source for the microorganisms to utilize. Such ores may be leached by using heterotrophic bacteria and fungi, which require an organic source as a source of energy and carbon for their growth (Jain and Sharma, 2004). The extent of iron removal from industrial silicate minerals depends on the mineralogy and distribution of iron in silicate rocks (Veglio, 1997).

The purpose of the present study was to investigate the effect of mineralogical composition of quartz sands on the extent of bacterial decomposition of iron surface impurities and on the yield or iron removal from different quartz sands.

2. Materials and methods

2.1. Quartz sands and equipment

Bioleaching was tested under laboratory conditions on quartz sands of the ore Šaštín (Q1), Vyšný Petrovec (Q2) and Plachtince (Q3). Partial element composition of Q1, Q2, Q3 is listed in Table 1.

Table 1. Chemical composition of quartz sands samples.

Concentration (%)	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	MnO
Q1	94.6	2.91	0.26	0.03	0.12	0.06	0.40	1.27	< 0.01
Q2	96.1	1.71	0.36	0.45	0.03	0.05	0.03	0.34	< 0.01
Q3	85.8	7.71	1.03	0.12	1.39	0.40	0.52	1.48	< 0.01

The elements of the solid samples were analyzed on the fused beads using an energy dispersive X-ray fluorescence spectrometer (Spectro X-LAB 2000, Germany). In addition, glass beads were prepared by fusion of the samples with Li₂B₄O₇ (1 g dried sample + 14 g Li₂B₄O₇). The x-ray diffraction of powdered samples was carried out with a Siemens D5005 diffractometer (Siemens, Germany) using CuK as radiation.

2.2. Laboratory bioleaching

The bioleaching experiments were carried out independently in 500 ml Erlenmeyer flasks containing 200 g quartz sands and 200 ml liquid medium. The medium contained 2.0 g K₂HPO₄, 1.0 g (NH₄)₂SO₄, 0.1 g CaCl₂, 0.075 g NaCl, 0.085 g NaNO₃, 0.2 g of urea, 0.75 g Na₂EDTA and 0.1 g of yeast extract, as well as 50 ml of glucose syrup A60 per liter media. The samples were inoculated with indigenous heterotrophic bacteria isolated by Trypticase Soy Agar (TSA, Difco). The flasks were incubated under static conditions for 3 months at 24°C, with the contents being stirred to homogenize the solution prior to sampling and chemical analyses. Fine-grained fractions were collected by stirring for 10s followed by decanting of the leach solution and by washing of quartz sands with distilled water. The fines were collected by filtration (0.2 µm pore size). The spend media (leachates) were sampled after 10 minutes of centrifugation at 10 000 rpm. The leachates were collected three times, always after the replacement of the culture solution (150 ml) during the bioleaching experiment. Appropriate abiotic controls did not receive an inoculum and organic source but were included under otherwise similar conditions. Bioleaching experiments and analyses were conducted in triplicate, and the presented data are the averaged values of the measurements.

3. Results and discussions

3.1. Laboratory bioleaching and elutriation of quartz sands

Naturally occurring quartz sands contain various fine iron, silicate, carbonate and clay minerals, which are coated on quartz grains or are impregnated in the silicate matrix as polyminerals mixture agglomerates. Three types of the different sand materials were used in laboratory tests: quartz sands with kaolinite, illite encapsulated and sealed by goethite (Q1), quartz sands with phengite, kaolinite encapsulated and sealed by siderite (Q2), quartz sands with glauconite encapsulated and sealed by clinoptilolite and Fe smectite (Q3). As can be seen from the results in Table 2, the extent of iron removal was higher in samples Q1 and Q2, where goethite and siderite with clay minerals covered quartz particles, than in sample Q3 with higher mica content in the form of glauconite.

Table 2. Comparison of iron content before and after bioleaching treatment in quartz sands.

Quartz sands	Fe ₂ O ₃ (wt.%) before bioleaching	Fe ₂ O ₃ (wt.%) after bioleaching	Fe ₂ O ₃ (wt.%) after bioleaching and washing
Q1	0.26	0.13	0.09
Q2	0.36	0.19	0.09
Q3	1.03	0.72	0.56

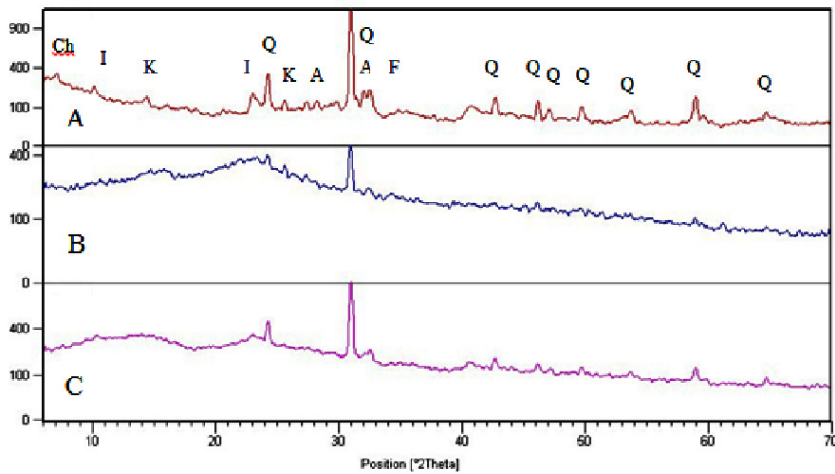


Fig. 1. X-ray analysis of the fine fraction elutriated from untreated quartz sands Q1 (A) and from bioleached quartz sands (B, C). Ch - chlorite, I - illite, K - kaolinite, Q - quartz, A -plagioclase, F - feldspar.

The presence of basal illite and kaolinite reflects in the fine fraction of Q1 with very low intensities in XRD patterns and confirmed the disordered structure of both minerals (Fig. 1A). However, the observed differences in XRD patterns of the fine fraction from quartz sands before and after bioleaching were evidently due to the formation of a fine amorphous phase (Fig. 1B, C). These amorphous fine-grained fractions (0.45%) with Fe-bearing and clay minerals were subsequently removed by washing process and the independent iron minerals (2.21%) were removed by magnetic separation (Fig. 2). Bioleaching resulted in a 50% decrease in the Fe content of quartz sands (Table 2), the subsequent washing process decreased the Fe content of the quartz sand from 0.13% to 0.09% Fe₂O₃ and the magnetic separation decreased the Fe content of the quartz sand from 0.09% to 0.076% Fe₂O₃ (Štyriaková et al., 2010).

The other types of quartz sands Q2 containing mineral impurities were also successfully treated with bioleaching and washing. In the process, poorly crystalline Fe-oxides that sealed siderite nodules were released due to the bacterial action from intergranular space of quartz sands. Bioleaching resulted in a 47% decrease in the Fe content

of quartz sands (Table 2) and the subsequent elutriation process decreased the Fe content of the quartz sand from 0.19% to 0.09% Fe_2O_3 . These Fe-oxides formed a fine-grained fraction with Fe-bearing minerals and also fine mica fraction after bioleaching were subsequently removed by washing process (Štyriaková et al., 2003).

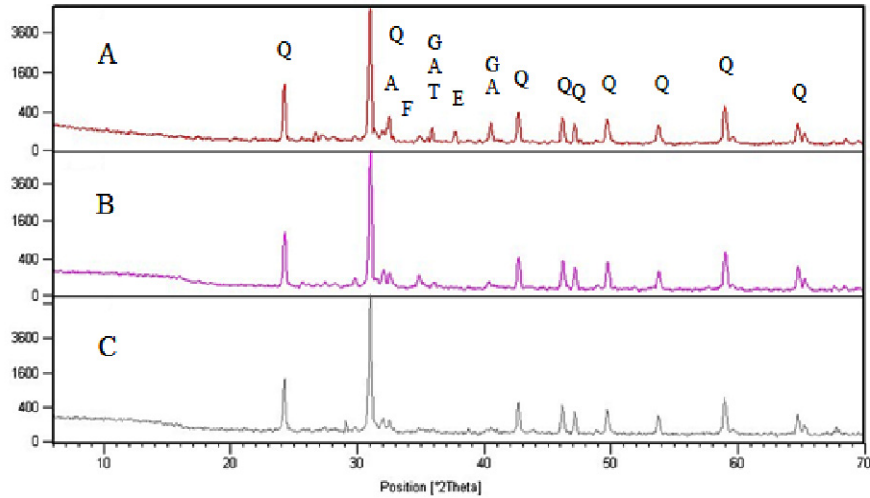


Fig. 2. X-ray analysis of the magnetic fraction of untreated quartz sands Q1 (A) and bioleached quartz sands (B, C). Q - quartz, A – plagioclase, F – K-feldspar, G – garnet, Am- amphibole, T – tourmaline, Gh- goethite.

Bioleaching of Q3 was also effective because it contained a higher iron concentration than Q1 and Q2 that is why resulted in about 30% decrease of the Fe content (Table 2). The iron concentration was dependent on glauconite associated with Fe.

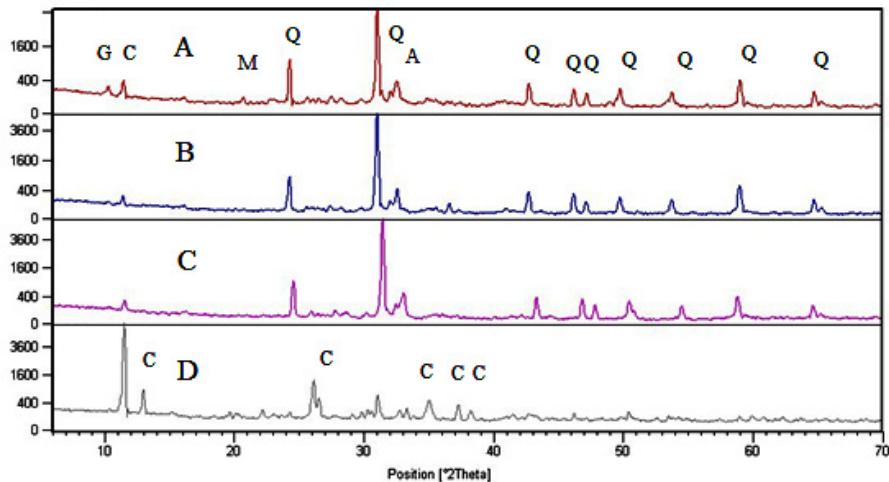


Fig. 3. X-ray analysis of untreated Q3 (A), magnetically separated Q3 (B), bioleached Q3 (C) and fine fraction elutriated from bioleached quartz sands Q3 (D). Q - quartz, A – plagioclase, M – Fe smectite, G – glauconite, C – clinoptilolite.

The Q3 is typically dominated by glauconite (10-12%) over Fe smectite (2-7%). The sample contained quartz, dominated over plagioclase (Fig. 3A). The part of glauconite has been removed by magnetic separation (Fig. 3B). After the bioleaching of the Q3 quartz sands in flasks, the Fe_2O_3 content decreased from 1.03% to 0.72%. Following the bioleaching, the washing of Q3 resulted in up to 0.56% decrease in the Fe_2O_3 content of the sample. The mineralogical composition of the removed finer fraction was significantly different from the quartz sands because the amount of quartz decreased, whereas clinoptilolite were enriched (Fig. 3D). It is questionable whether the slight differences in mineralogical composition before and after bioleaching (e.g. the increase of the intensity of clinoptilolite) can be attributed to bacterial decomposition or releasing of clinoptilolite and bioformation of the clinoptilolite fine fraction (Fig. 3A and 3C).

The bacteria assisted in releasing the poorly ordered minerals from the surface of quartz particles via dissolution of amorphous Fe oxyhydroxide. This process of quartz sand bioleaching includes bacterial adhesion to the surface of quartz particles and production of organic acid into the iron–silicate bonds of surface minerals, because the pH decreased from 7 to 4 and the surface of the quartz particles was cleaned. (Štyriaková et al., 2012).

Subsequent smelting of the Q3 sample before magnetic separation confirmed visibly the high iron content. The magnetic separation removed 10% of glauconite with a change of brown color and the sample of white color of the bioleached quartz sands confirmed improvement quality with bacterial leaching. Bioleaching caused Fe dissolution and decomposition of the cementing iron oxyhydroxides and the formation of fine-grained brown particles as a discretely separate fraction. This fine-grained fraction was elutriated from bioleached quartz sand. Concurrently, the treated quartz sand changed to white color.



Fig. 4. Smelting samples of Q3 before treatment, followed by magnetic separation and bioleaching with washing process.

4. Conclusions

Naturally occurring industrial minerals contain the unrequested admixture of iron and silicate minerals as coatings on grains or impregnated in their matrix. The bioleaching processes in combination with other methods such as washing and electromagnetic separation can increase the iron removal from quartz sands. Bioleaching is predominantly acting in the dissolution of surface layers of the fine iron minerals and for the release of impregnated independent iron and silicate minerals. The following washing process removed the fine particles of minerals and magnetic separation and removed the independent iron minerals with it.

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