

Optimization approach for the quartz industry by using sands from Ravno, Slovenia

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Abstracts:

Sands from the Ravno deposit, Slovenia, were characterized to evaluate their potential for high-purity quartz production, which is a critical raw material for EU industries. X-ray powder diffraction, chemical analyses, and quantitative mineralogy by liberation analysis were carried out. The quartz content is approximately 90%, with feldspar (~5%), rutile (~1%), zircon (~1%), and minor other minerals. The current particle top size is 500 µm. Since the material is already relatively fine, crushing can be skipped, allowing for significant cost savings. Process development was focused on selective flotation using Clariant reagents, combined with gravity separation (Wilfley table and Falcon separators) to remove high-density impurities and upgrade the quartz to high-purity standards.

1. Introduction

High-purity quartz (HPQ) is an essential industrial mineral used in advanced technologies such as photovoltaic glass, semiconductors, optical fibers, ceramics, and foundry products. These applications demand low impurity levels, making beneficiation vital for upgrading natural quartz (1, 2). Quartz deposits often contain gangue minerals such as feldspar, mica, clay, zircon, rutile, iron oxides, and titanium phases, which appear as isolated grains or inclusions. Beneficiation depends on mineral liberation, grain associations, and particle size. Traditional methods like grinding, flotation, magnetic separation, and chemical leaching are effective but costly, energy-intensive, and environmentally challenging (3,4). Gravity concentration offers a lower-energy alternative when mineral liberation is sufficient (2-6). Advances in process mineralogy, such as Mineral Liberation Analysis (MLA), enable detailed studies of mineral distribution and association, allowing more precise flowsheet design. Effective separation also depends on particle shape; flat minerals like muscovite mica can hinder gravity separation (7,8). Enhanced gravity separators, such as Falcon units, improve fine particle recovery by applying centrifugal force. This study evaluates KU-1 quartz ore beneficiation through mineralogy, gravity tests, statistical optimization, and energy analysis. It aims to develop an

energy-efficient flowsheet with potential regrinding, combining mineralogical insights with process optimization to produce high-purity quartz cost-effectively from KU Slovenia ore.

2. Materials and Methods

Analytical Methods

Particle size distribution analysis (PSD)

The particle size distribution was determined by standard sieve analysis. A representative 100 g portion of feed was sieved through a series of screens to quantify size fractions relevant to gravity separation performance. Mass retained on each sieve was measured, and cumulative size distribution curves were generated. The feed F80 was calculated by interpolating cumulative passing data. The PSD results were used to determine suitable size fractions for gravity treatment using the shaking table and Falcon concentrator.

Table 1: The Feed PSD of KU ore

Size fraction (μm)	Mass (%)
710–500 μm	0.20
500–300 μm	9.05
300–200 μm	48.34
200–106 μm	13.77
106–53 μm	23.42
<53 μm	5.23

Chemical analysis (XRF)

The bulk chemical composition of the feed and gravity-separation products was analysed using X-ray fluorescence (XRF). Samples were dried, ground, and prepared as fused beads or pressed pellets before analysis. Major oxides such as SiO_2 , Al_2O_3 , Fe_2O_3 , and K_2O were measured. The chemical data were used to assess the efficiency of quartz upgrading and impurity removal during gravity-concentration experiments. The quartz content is approximately 90%, with feldspar (~5%), rutile (~1%), zircon (~1%), and minor other minerals.

Mineralogical analysis (XRD)

X-ray diffraction (XRD) analysis was conducted to determine the mineral phases in the sample. Powdered specimens were scanned within a suitable 2θ range using $\text{Cu-K}\alpha$ radiation. Reference databases were used to identify phases. The results confirmed quartz as the dominant mineral, with feldspar and mica as impurities, justifying additional mineralogical analysis using MLA.

SEM analysis

Energy-dispersive X-ray spectroscopy (EDS) analysis was performed to determine the elemental composition of the sample. The results indicate in fig 1 that the material is dominated by oxygen (55.9 wt.%) and silicon (29.4 wt.%), suggesting a silicate-rich composition. Aluminium accounts for 4.6 wt.% of the sample.

Minor elements detected include iron (1.6 wt.%), potassium (0.7 wt.%), titanium (0.2 wt.%), magnesium (0.1 wt.%), and calcium (0.1 wt.%). These elements occur at low concentrations and are likely associated with accessory mineral phases. The low measurement uncertainties indicate good analytical reliability.

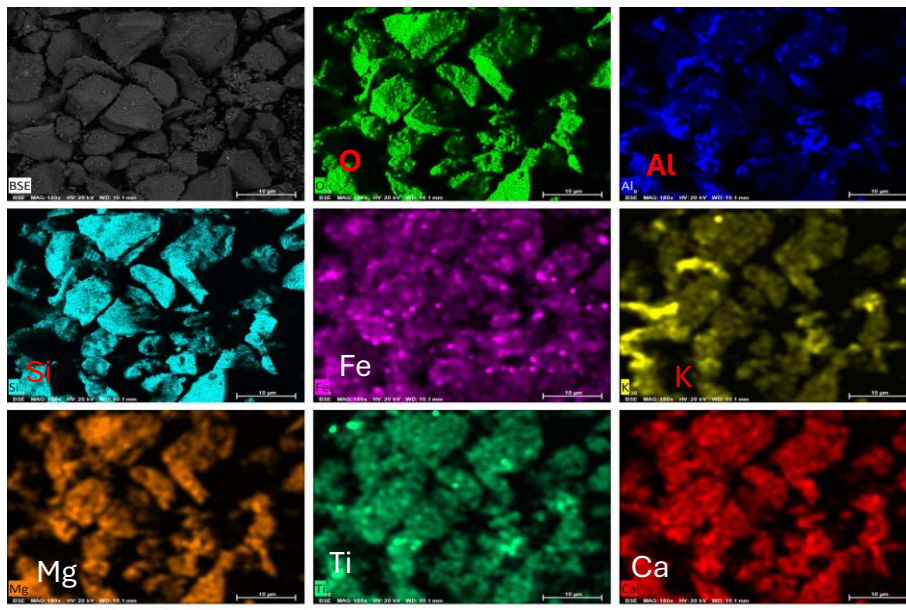


Fig. 1 SEM analysis of KU ore

LA-ICP-MS analysis

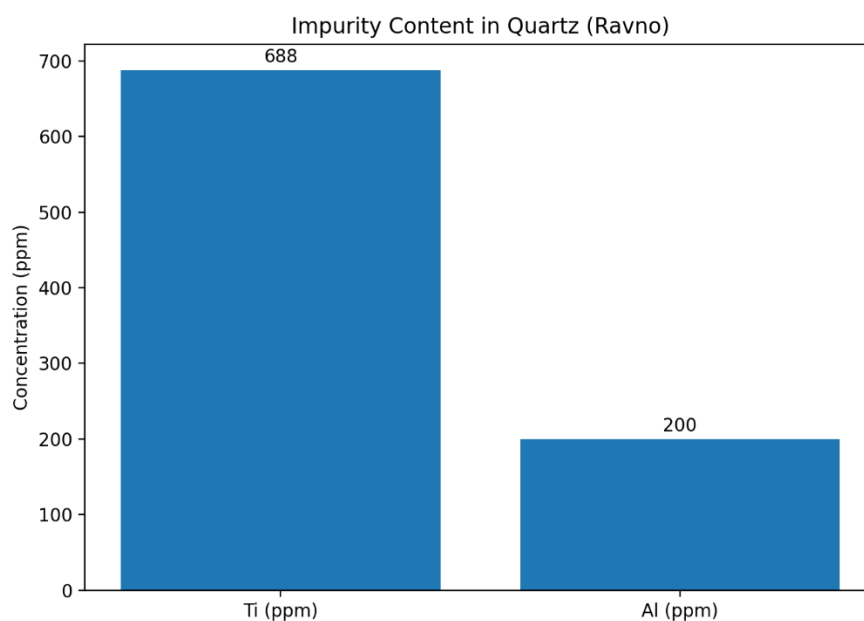


Fig. 2: Laser ablation of of KU ore

Preliminary LA-ICP-MS results show Fe is usually under th detection limits, while in Ravno, Ti is higher (averaging 688 ppm). Al inBellpuig has average values of 170 ppm, while in Ravno they are somewhat higher.

Mineral Liberation Analysis (MLA)

MLA analysis was conducted to quantify modal mineralogy in Table 2, mineral associations, and quartz liberation characteristics. Polished sections were prepared from representative size fractions and analysed using automated SEM-based MLA.

Liberation analysis was performed using a $\geq 95\%$ quartz grain threshold to classify liberated quartz. Mineral-locking relationships were also determined to identify impurity associations, particularly in quartz–mica composites (7-10).

Table 2: Mineralogy and gravity feasibility of KU ore.

Mineral	Density (g/cm ³)	CC vs Quartz	Avg Aspect Ratio	Shape Character	Gravity Feasibility	Separation
Quartz	2.65	1.00	~1.5	Equant	Reference mineral	
Muscovite	2.80	1.06	~2.0	Platy– elongated	Difficult (entrainment)	
Plagioclase	2.70	1.02	~1.6	Sub-equant	Very difficult	
Chlorite	2.80	1.06	~1.9	Slightly platy	Difficult	
Orthoclase	2.60	0.98	~1.7	Sub-equant	Not separable	
Dolomite	2.85	1.08	~2.1	Slightly elongated	Difficult	
Tourmaline	3.20	1.21	~1.7	Equant– elongated	Moderate	
Biotite	3.09	1.42	~1.6	Platy– elongated	Difficult (entrainment)	
Rutile	4.25	1.60	~1.5	Equant	Good separation	
Ilmenite	4.70	1.77	~1.7	Sub-equant	Good separation	
Zircon	4.65	1.75	~1.5	Equant	Good separation	
Iron oxide	5.0–5.3	~2.0	~1.7	Sub-equant	Excellent separation	

3. Results and discussions

The mineralogical composition of the feed material before and after gravity separation shows a clear improvement in quartz purity. Initially, the sample consisted of approximately 90% quartz, 5% feldspar, and minor heavy minerals including rutile (1%), zircon (1%), and other impurities (~1%). After processing with a shaking table and Falcon concentrator, the proportion of quartz increased to about 91%, reflecting the effective removal of dense mineral phases. Rutile and zircon contents were significantly reduced to around 0.3% each, while other minor impurities decreased to approximately 0.4%. In contrast, feldspar content remained largely unchanged due to its similar density to quartz, making it less responsive to gravity-based separation. Overall, the results demonstrate that gravity concentration techniques are effective in selectively removing high-density impurities, leading to a measurable enhancement in quartz purity.

Table 3: After Shaking tables and Falcon tests experiments

Mineral	Before (%)	After (%)	Change (%)
Quartz	90.0	93.0	+1.0
Feldspar	5.0	5.0	0.0
Rutile	1.0	0.3	-0.7
Zircon	1.0	0.3	-0.7
Others	1.0	0.4	-0.6

Flowsheet Development

Based on mineralogical and experimental results, the proposed processing flowsheet includes:

1. Size classification
2. Shaking table treatment for coarse fractions
3. Falcon concentration for fine fractions
4. Final cleaner stages

This integrated approach maximizes quartz recovery while minimizing energy consumption and impurity carryover.

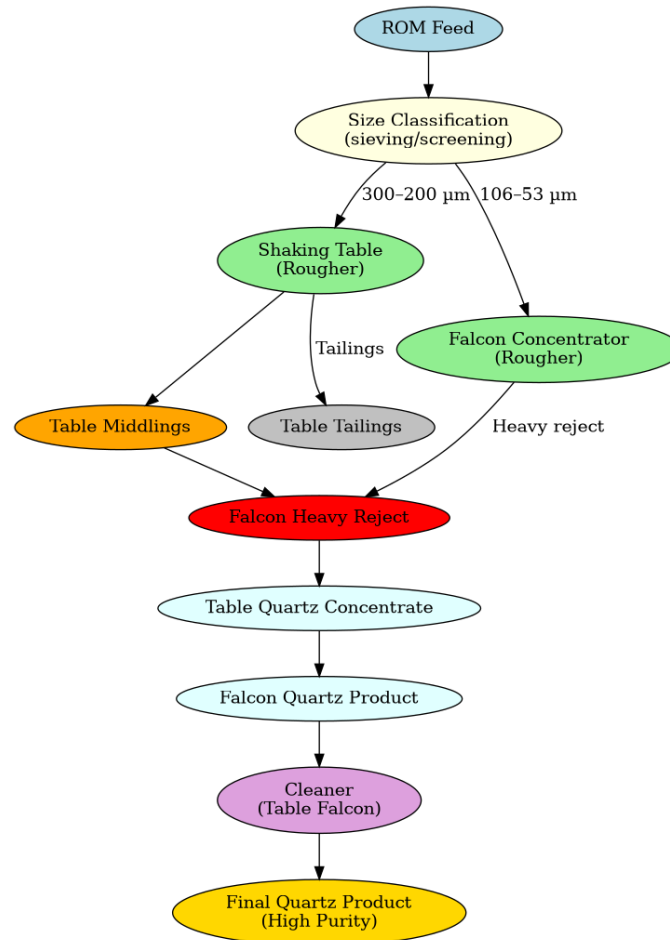


Fig. 3: Proposed flowsheet of KU ore

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