minerals

Article

Awaruite, a New Large Nickel Resource: Flotation under Weakly Acidic Conditions

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Supplementary Material

1. Equipment Photos

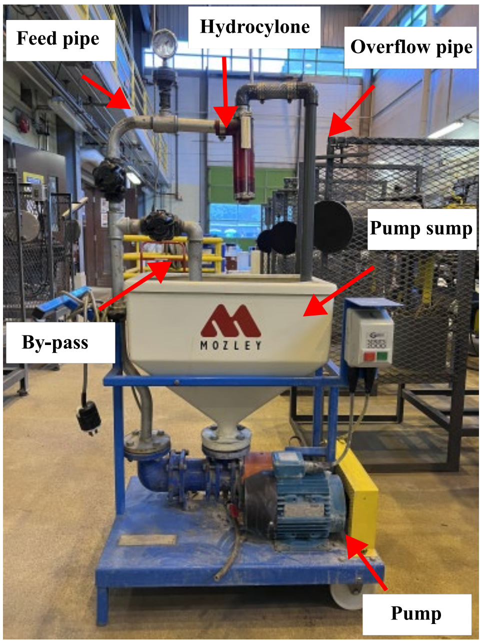

Figure S1. Photo of Mozley C125 two-inch (5.1 cm) stub hydrocyclone mounted in a standard Mozley test rig.

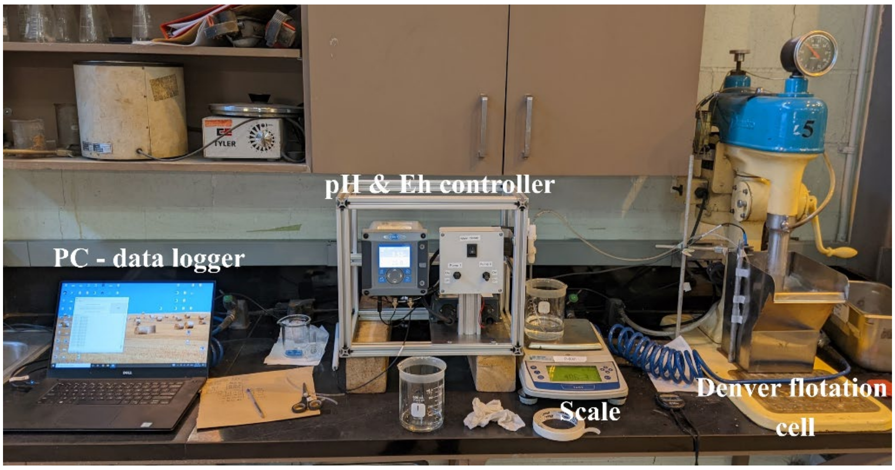

Figure S2. Bench scale set-up including the pH-Eh control system and the flotation cell.

2. Desliming Data

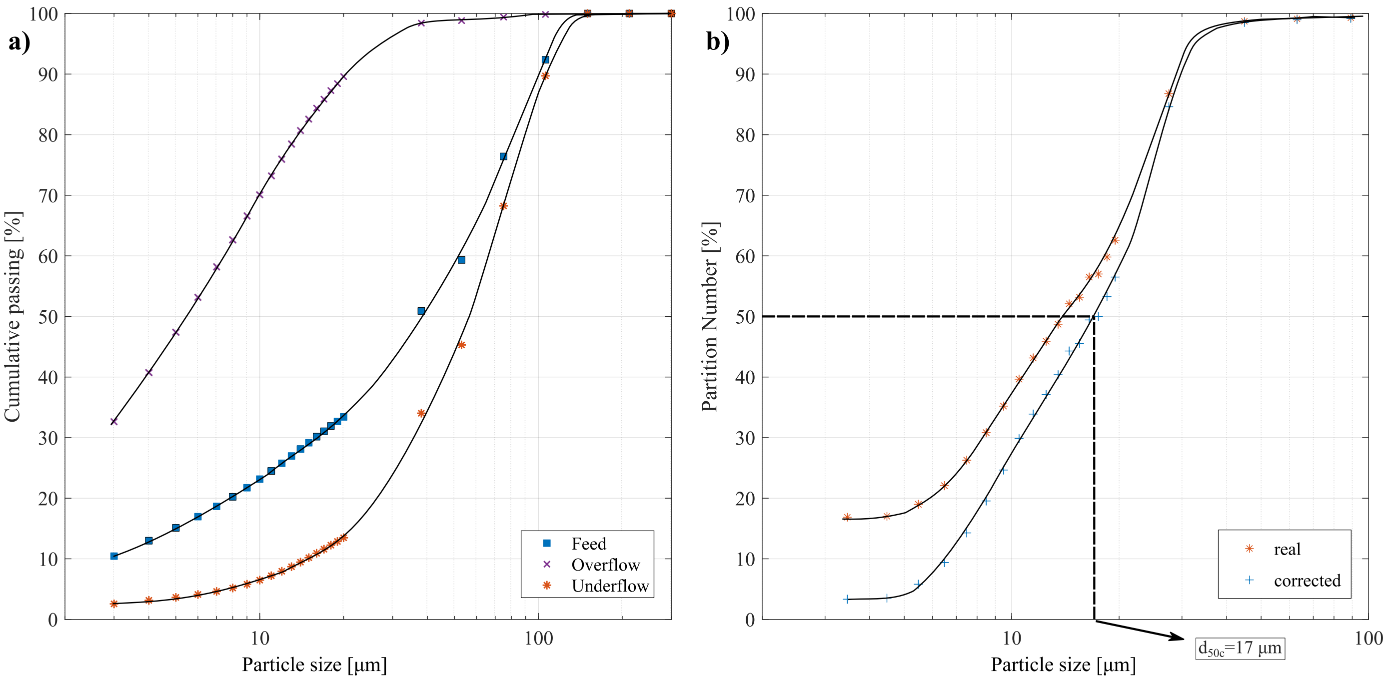

Figure S3. a) Particle size distribution of the Baptiste sample after 15 min grinding (feed to the desliming process), and of the underflow and overflow of the desliming process; b) corrected and uncorrected partition curves for the hydrocyclone desliming tests.

Table S1. Operating parameters for the hydrocyclone desliming tests.

Parameters [unit]	**Value**
Cyclone diameter [mm]	51
Stub cone diameter [mm]	4.5
Vortex finder diameter [mm]	8
Pressure [kPa]	207
Feed flow rate [$L.min^{-1}$]	20
Feed dry solids density [$g.cm^{-3}$]	2.7
Feed slurry solids [wt.%]	8.0
Underflow solids [wt.%]	14.5
Overflow solids [wt.%]	7.2
Water split to underflow [wt.%]	16.2
Mass split to underflow [wt.%]	73.8
Hydrocyclone cut-point, d_{50c} [µm]	17
Imperfection, I	0.26

3. Sulfur Recoveries

The maximum sulfur recovery achieved for all the conditions applied was lower than 40% (Figure S4). Pentlandite, millerite and heazlewoodite float well in a wide range of pH values with xanthates [16,37,38]. Furthermore, the flotation under weakly acidic conditions, adjusted with sulfuric acid, can be beneficial for their flotation recovery and selectivity in serpentinite ores [12]. The low recoveries could be linked to the lack of surface liberation of nickel sulfides.

The mechanism behind the effect of acid is a subject of debate. It has been suggested that the acid promotes the formation of a hydrophobic sulfur layer, or removes hydroxides formed on the surface of the minerals due to oxidation, or both [39]. Also, acid can act as a dispersant and depressant for serpentine minerals, thus minimizing the detrimental effect of slimes into the sulfide flotation [40,41]. Different explanations have been provided for the dispersing effect of acid. In this case, sulfuric acid reacts with the serpentine slimes, leaching selectively its internal brucite layer and leaving a silica rich layer on its surface. The overall recovery of the four concentrates is not considerably different for the distinct pH conditions. The effect of pH on the nickel recovery is not equally observed in the sulfur recovery. For the deslimed sample the curves for the five pH conditions are not considerably different, but the overall recoveries are slightly higher than those achieved for the whole sample (Figure S4.b). This increment in the recovery can be also explained by the benefits associated to the removal of the slimes as previously mentioned.

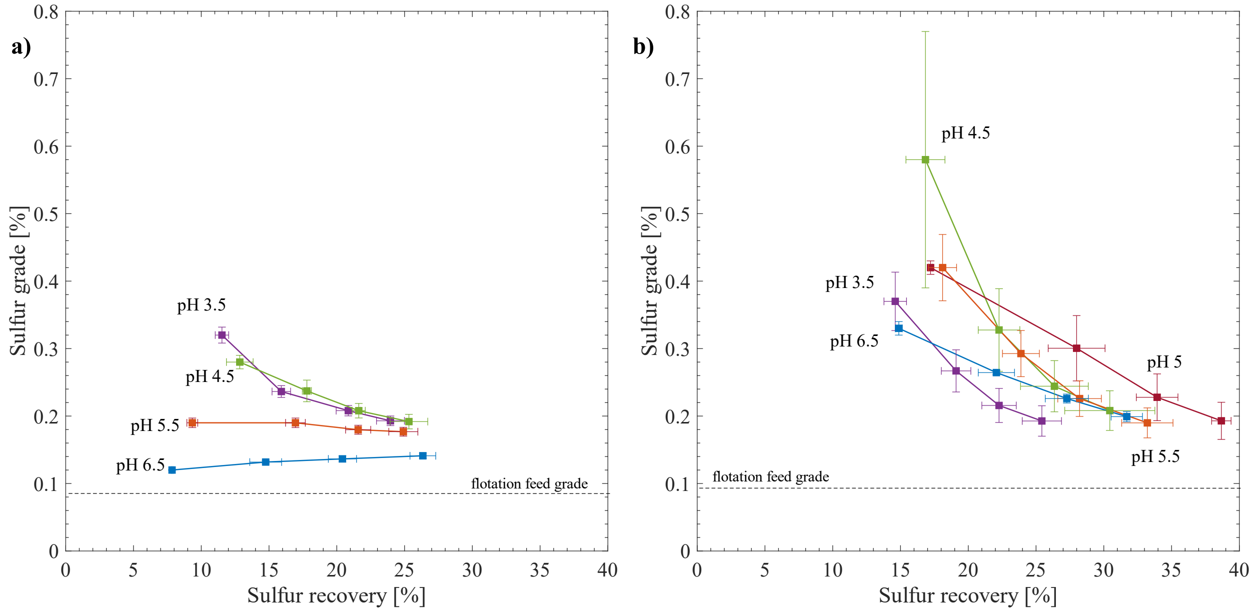

Figure S4. Sulfur grade vs. recovery at different pH values: a) whole sample, b) deslimed sample. Error bars represent one standard deviation based on duplicate tests.

4. Acid Consumption Profiles

The reaction of acid with the minerals depends not only on the kinetics of dissolution but also on the quantity of surface exposure. The surface area of the slimes is considerably larger than the surface area of the deslimed sample. Even though the slimes are only one fourth of the feed material, they contribute with almost two thirds of the acid consumption. The flotation test performed in the slimes stream at pH 4.5, resulted in an acid consumption of 61.2 kg/ton of slimes, which corrected by the proportion of slimes in the feed sample leads to a consumption of 16.7 kg/ton of circuit feed.

Figure S5 shows the time profiles for pH and acid consumption during flotation tests for the whole and deslimed samples, and the slimes. Half of the acid is consumed to adjust the pH to the desired level and the rest is required to maintain the pH for the duration of the test. For the whole sample, the first half of the acid (16 kg/ton) is consumed in the first 3 min while lowering the pH to 4.5, and the other half is consumed during the conditioning and concentrate collection in the remaining time (30 min).

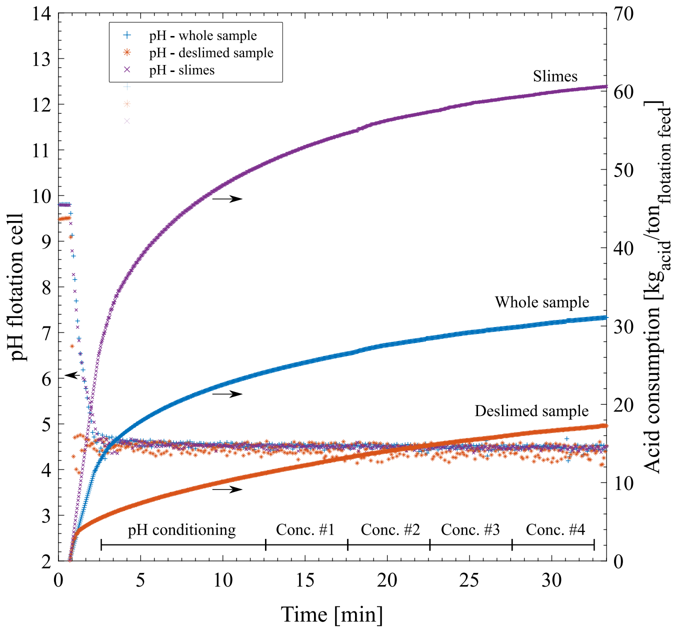

Figure S5. Time profiles of pH and acid consumption for the whole and deslimed sample, and the slimes. The different stages during the flotation process are shown next to the x-axis, the time associated to each conc (Conc. #) includes collector and frother conditioning (3 min) and concentrate collection (2 min).

5. Rougher-Cleaner Flotation

Before cleaning, the rougher concentrates were wet reground in a rod mill for 20 min. The P_{80} of the reground concentrate for the whole sample tests (without desliming) was 22 µm, and the P_{80} for the deslimed sample tests was 28 µm.

Table S2. Metallurgical balance of the rougher-cleaner circuit for the whole sample.

Products	Mass [%]	Element content [%]			Distribution [%]		
		Ni	Fe	S	Ni	Fe	S
Final concentrate	0.1	45.20	16.08	3.13	31.1	0.3	4.7
3rd cleaner tail	1.1	2.46	5.36	0.47	14.3	0.9	5.9
2nd cleaner tail	7.5	0.27	4.77	0.13	10.7	5.5	11.2
1st cleaner tail	8.7	0.19	4.63	0.11	8.7	6.2	11.1
Rougher Tail	82.6	0.08	6.80	0.07	35.2	87.0	67.1
Feed	100.0	0.19	6.45	0.09	100.0	100.0	100.0

Table S3. Metallurgical balance of the rougher-cleaner circuit for the deslimed sample.

Products	Mass [%]	Element content [%]			Distribution [%]		
		Ni	Fe	S	Ni	Fe	S
Final concentrate	0.1	39.50	15.69	5.72	26.8	0.4	11.0
3rd cleaner tail	0.7	3.63	6.71	0.43	12.7	0.8	4.2
2nd cleaner tail	4.6	0.40	5.71	0.14	9.1	4.6	8.9
1st cleaner tail	5.4	0.28	5.97	0.1	7.5	5.7	7.5
Rougher Tail	62.3	0.10	6.57	0.07	29.5	71.6	60.8
Slimes	26.9	0.11	3.68	0.02	14.4	17.0	7.5
Feed	100.0	0.20	5.83	0.07	100.0	100.0	100.0