Heap Bioleaching of Copper-Nickel Ores in the Arctic

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Abstract. This paper researches the effectiveness of heap leaching for processing the sulfide raw materials in Murmansk Oblast. It studies the kinetics of how metals are extracted into the solution, as well as the peculiarities of chalcopyrite dissolution. The paper shows that leaching destroys the grains, making them into fine particulate matter, which ultimately jeopardizes solution filtering. Use of recycled solution makes the leaching process more cost-effective.

1. Introduction
To date, the world has over 400 deposits of copper and nickel ores, most of which are sulfide ores. Sulfide ores are the source of ~65% of the 1.35 million tons of nickel produced worldwide per annum (~700 thousand tons for copper) [1]

At the same time, metal producers have to use hard-to-enrich and substandard ores because ore quality is declining. Use of physical enrichment methods like flotation, gravitational or magnetic separation is not cost-effective in application to low-quality ores [2]. Heap leaching involving microorganisms might be efficient for the processing of such ores. Biohydrometallurgical technologies for sulfide ore and concentrate processing are quite common [3]. To date, the world has industrial facilities that extract copper and uranium, process gold-containing ores and concentrates [4-6].

Most of such facilities are located in warmer regions, where the climate is favorable for such process. However, leaching has also been implemented in harsher regions [4,7-10], meaning the technology could also be used for sulfide processing in the Arctic.

Murmansk Oblast has a number of copper and nickel sulfide ores that are currently not productive because conventional processing technologies are not feasible there [11]. The goal hereof was to research heap leaching of sulfide ores and to rationalize the application of this technology for the purpose of activating the unused deposits in Murmansk Oblast.

2. Subject matter and methods
For research, the team picked two sites located in Murmansk Oblast: Allarechensk anthropogenic deposit (‘the AD’) and Nude II.

The AD ores mainly consist of pyrrhotine, pentlandite, and chalcopyrite, which are closely paragenetically related to magnetite. As the primary deposit has already in operation, the ores have...
been crushed, diversifying it in terms of grain size. Most of the ore material belongs to the grain-size class of –150 +10 mm. Nickel concentration is significantly lower in ores sized <40 mm, from 0.53% in the –40 + 25 mm class to 0.16-0.18% in the <0.10 mm class [12]. Copper concentration does not vary much from class to class, ranging from 0.28% to 0.65%.

Nude II ore minerals include pyrrhotine (40% to 50%), chalcopyrite (20% to 30%), pentlandite (10% to 15%), and pyrite (5% to 10%) [13]. Besides, this ore also contains a substantial amount of magnetite (10% to 30%). Pyrrhotine forms the sulfide matrix of ore and features ingrown pentlandite. Magnetite forms hypidiomorphic grains in pyrrhotine. Chalcopyrite is broadly present in the form of inclusions in pyrrhotine, sulfides are present as fine and dust-like shots in silicates (orthopyroxene and plagioclase) [14].

For laboratory experiments involving heap bioleaching, the researchers had earlier isolated acidophilic chemolytotrophic bacteria resistant to high concentrations of heavy metals and capable of functioning at low pH [15].

Research was carried out at ambient temperatures of 18ºC to 20ºC; ore was ground to –5+2 mm, and samples of 800 g (AD) or 200 g (Nude II) were placed in glass percolators. The AD sample had 5.8% Ni, 2.9% Cu; the Nude II sample had 1.97% Ni and 0.54% Cu. Ores in the percolators were irrigated with a bacterial solution to an S:L ratio of 4:1. The solution was recycled; i.e. before the next application to an ore pile surface, it was diluted with a fresh solution by two thirds. During the percolator experiment, the research team monitored pH and Eh as well as Fe\textsuperscript{3+} and Fe\textsuperscript{2+} concentrations. The AD ore experiment lasted 60 days, and the Nude II experiment took 100 days.

Copper and nickel concentrations in the productive solutions were measured by the PND F 14.1:2:4.140-98 standard using atomic absorption spectroscopy with electrothermal atomization (ETAAS).

3. Results

X-ray diffraction analysis (XDA) of the original AD sample showed the ore consisted mainly of pyrrhotine carrying inclusions of pentlandite and secondary ore minerals. The research team reported reflexes of pyrrhotine, pentlandite, and chalcopyrite.

Chemically, it was iron and silicon oxides as well as sulfur that accounted for the bulk of the ore, see Figure 1. AD ore had much greater proportions of iron oxides and elemental sulfur than its Nude II counterpart. Aside from positive effects on bacterial life, high iron content can create a passivating layer on grain surface due to the deposition of hydroxides, which inhibits the extraction of the desired metals.

60 days of leaching extracted 4.2% of nickel and 1.0% of copper from the AD ore. Nickel concentration in the solution peaked at 1179 mg/l within five days of the experiment, see Figure 2. Further in the experiment, nickel concentration was gradually dropping to a minimum of 149 mg/l. After 30 days, the concentration of metal in the recycled solution decreased dramatically, and so did filtering performance. For this reason, the ore layer was stirred in the middle of the experiment to raise the copper concentration to 80 mg/l and the nickel concentration to 380 mg/l.
After leaching, ore sample bore reflexes of the sale sulfides; however, their peaks were flattened. This suggests that leaching engages the bacterial solution in an intensive interaction with sulfides. XDA did not detect iron hydroxides that could form passivating layers. Solution filtering likely stopped because dust particles clogged the filter. The chemistry of the AD ore was still dominated by iron and silicon oxides as well as sulfur after leaching.

The oxidation-reduction potential of productive solutions varied from 417 mV to 520 mV throughout the AD ore experiment. This relatively low ORP was due to bivalent iron being released from chalcopyrite and the deposition of trivalent iron. The Fe$^{3+}$ concentration in the productive solutions lowered from 14.2 g/l to 10.7 g/l as the experiment went on (the initial value was 16.4 g/l). pH of the solutions, whether fed to the column or productive, varied from 1.95 to 2.01, which was optimal for the bacteria used in leaching.

By the end of the experiment, 15.3% of nickel and 10.9% of copper was extracted from the Nude II ore. Nickel concentration in the solution peaked on Day 22 at 884.0 mg/l; copper concentration peaked on Day 25 at 220 mg/l, see Figure 3. The fact that the bacterial solution indeed interacted intensively with the Nude II ore was confirmed by chemical analysis of leached ores. Elemental sulfur only accounted for 9.7% of the residue compared to 14.9% in the original sample.

Bacterial solution and Nude ore interaction showcased interesting curves of copper extraction. Copper concentration in the solution did not exceed 60 mg/l for the first 25 days of the experiment, then went up dramatically. This might be due to the specifics of chalcopyrite (CuFeS$_2$) dissolution, as this mineral is not easily breakable with acidic or alkaline solutions. The mineral started to interact
with the bacterial solution intensively only after 20 days. Post-leaching XDA revealed reflexes of pyrrhotine and pentlandite (both are nickel concentrators); however, it did not detect copper sulfides.

The productive solutions had an average ORP of 522 mV, which was higher than that of the AD ore. pH varied from 1.84 to 2.20 during the experiment.

4. Conclusions
Laboratory percolation tests proved the technology effective for processing ore from Murmansk Oblast sites. Nude II ore demonstrated a more intensive leaching process: 15.3% of nickel and 10.9% of copper was extracted by the end of the experiment.

The isolated bacteria were resistant to low pH and high metal concentrations in the solution, making them suitable for heap leaching. Use of recycled solution was proven feasible, making heap leaching a cost-effective method.

Leaching did not produce passivating layers of iron hydroxides. The authors believe it was filter clogging that inhibited leaching over time, meaning the ore layer needs to be stirred from time to time for better permeability. There is a need to find a method to intensify metal release in the later stages of the process. Ore from both deposits has similar copper leaching kinetics; there needs to be found a way to increase its release.

5. References
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