Process Update on Dynamic Heap Bioleaching of a Black Schist Ore

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Abstract

The Terrafame multi-metal mine, located in Sotkamo, Finland, utilizes heap bioleaching to extract metals from black schist ore. The ore leached at the mine is a complex sulfide ore with pyrrhotite and pyrite as the main sulfides (5–15 w-% each). In addition, the ore contains 5–10 w-% graphite. The valuable metals in the ore deposit, Ni, Zn, Cu, and Co, are in pentlandite/pyrrhotite, sphalerite, chalcopyrite, and pyrite, respectively. The heap leaching process is divided into two steps: dynamic primary leaching and multi-lift secondary leaching. The primary leaching stage containing a total of 24 to 28 million tonnes of ore takes approximately 15 months. If the primary leaching process is seen to be continuing well after 15 months, the leaching time is lengthened by extending the leaching pad. Extensions of the primary leach pads were started with a 150 m area for two of the four pads in 2021. Construction of new secondary leaching areas will also commence in future. Explorations in the Kolmisoppi mine reserve are ongoing, and mining will extend to Kolmisoppi in the future.

Operation of the dynamic primary pads started in 2008, and the reclaiming of the ore from the primary to the secondary pads commenced in 2010. A review of the operation was presented at the Heap Leach Mining Solutions 2016 Conference in Lima, Peru, by Antti Arpalahti. The seventh round of operation on the primary leaching pads will start in the summer of 2022. In 2021, 28,582 tonnes of nickel and 54,353 tonnes of zinc were produced, and the net sales were EUR 378.4 million. The production of nickel and cobalt sulfates for the battery industry started in 2021, and is increasing. In 2021, the production of battery chemicals made up 7% of the total sales. Planning for the uranium recovery plant update and start-up is ongoing.

Increased aeration capacity in the primary heaps has been one of the contributors to the enhanced leaching. Extra air feed into the heaps accelerates the leaching reactions and increases heat formation and evaporation. Therefore, primary heaps contribute significantly to control of the water balance. The solution volume in the mine area has settled in the targeted level. Since 2015, the solution balance has been also

controlled with a discharge pipeline. This paper provides an update on the current process developments at Terrafame mine, ongoing production and operation ramp-up, and future production plans, including battery chemical production and the recovery of uranium.

Introduction

Terrafame mine (previously called Talvivaara mine) is located in Sotkamo, Eastern Finland. Geological mapping of the mine area was started in the early 1900s by the Geological Survey of Finland (GTK), and several Finnish companies carried out explorations at the site in the 1950s and 1960s.

After metallurgical sampling of the deposits and investigation of the exploration and research data, heap bioleaching was chosen as the most economical option to extract the metals from the ore.

Operation of the dynamic primary pads started in 2008, and reclaiming of the ore from primary to secondary pads commenced in 2010. Since 2015, the mining operation has been in a new commissioning phase. The operation ramp-up has been successful, and the seventh round of operation on the primary leaching pads will start in the summer of 2022.

Extra air feed into the heaps accelerates the leaching reactions and increases heat formation and evaporation. Therefore, primary heaps contribute significantly to the water balance control. The solution volume in the mine area has settled at the targeted level. Since 2015, the solution balance has been also controlled with a discharge pipeline.

Terrafame process update

Mineral resources

The mineral resources of Terrafame Oy consist of two Ni-, Zn-, Co-, and Cu-bearing deposits, Kuusilampi and Kolmisoppi (Figure 1). Currently the mining takes place at Kuusilampi, in an open pit mine.

Ni-Zn-Co-Cu mineralizations occur within the Kainuu Schist Belt in Central Finland. The schist belt consists mainly of quartzites, mica schist, and black schist. The schist belt lies unconformably on the Archaean basement gneiss complex.

The Kuusilampi orebody has overall dimensions of approximately 2,500 m × 100 to 400 m, and the Kolmisoppi has dimensions of approximately 4,000 m × 50 to 300 m. The extensions in the depth are open under the level of 300–500 m.

Previous mineral resource and ore reserve estimates were published in 2020. Since then, Terrafame Oy has drilled around 24 km of diamond core drilling and a 0.7 km geotechnical diamond core at the Kuusilampi and Kolmisoppi deposit.

As of 2022, the mineral resources amount to 1,453 million tonnes of ore at 0.26 %Ni, 0.54 %Zn, 0.019 %Co and 0.15 %Cu.

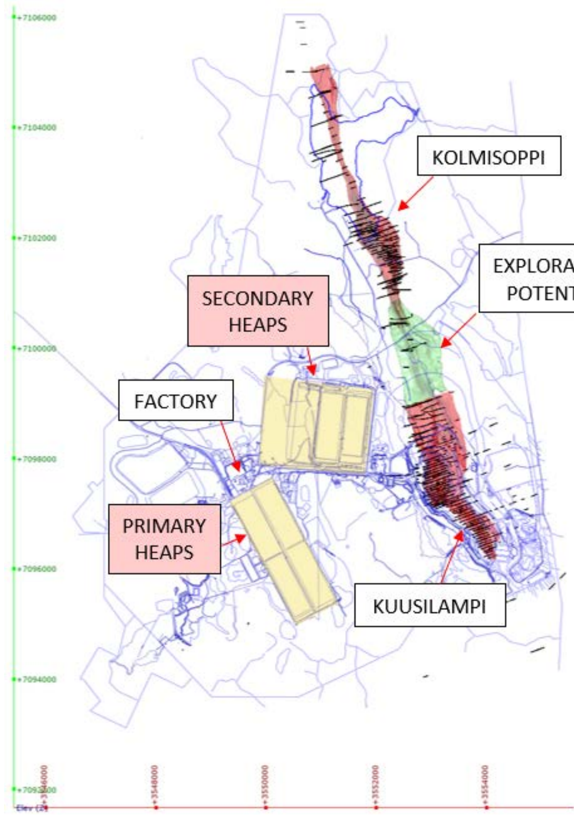

Figure 1: Overview of Terrafame's industrial area, highlighting the location of Terrafame's mineral resources (Kuusilampi and Kolmisoppi) and primary and secondary leaching pads

Primary heap leaching area

Extension of the primary leaching residence time

It has been observed that primary leaching process performance continues at a good level after the original 18-month residence time at the primary leaching pad. In 2020 it was decided to increase said residence time by extending the primary leaching pads towards the south (greater area and same mining rate, leading to extended residence time in leaching). The primary leach pads were extended in length during 2021 by 150 m. The ore tonnage in the primary area has since increased to about 1,5 million tonnes, and the residence time (under normal mining rates) by approximately 30 additional days, prior to the start of reclaiming operations (Figure 2).

With these actions Terrafame strengthens the share of the primary leaching production compared to total production (primary plus secondary), thus leading the operation towards more efficient production of nickel and cobalt sulfates, and zinc sulfide. In addition, copper production benefits from the increased leaching time in the primary phase.

As a next step, planning of additional extensions of primary heaps is ongoing, and it is anticipated that detailed planning will begin to gain momentum during 2022.

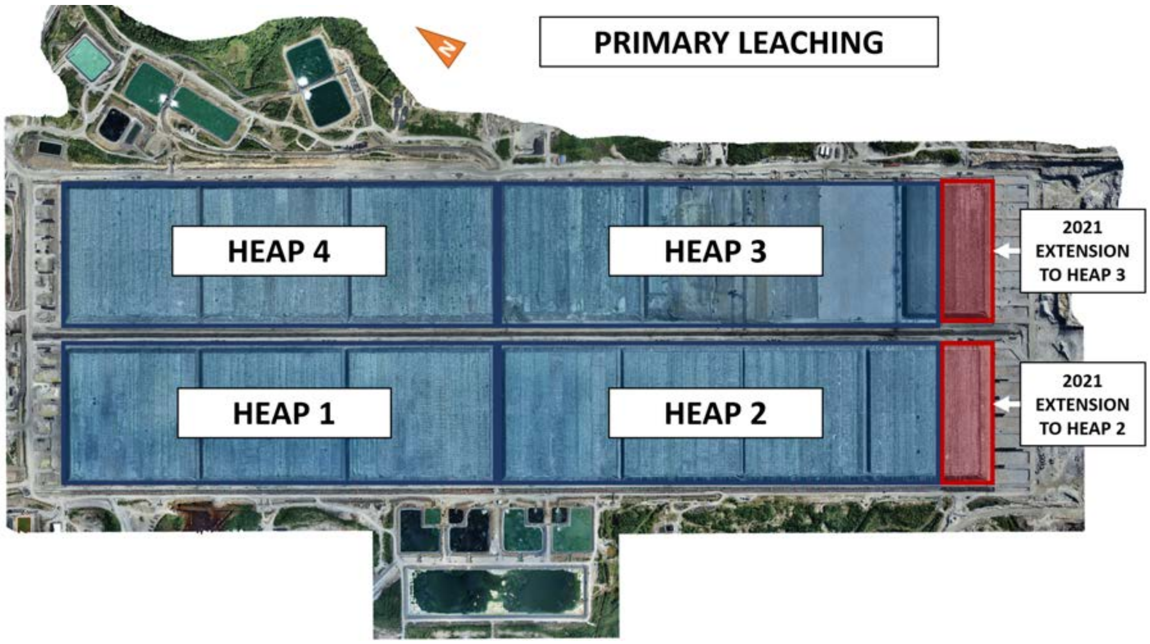

**Figure 2: Overview of the primary leaching stage.
The extension of the leaching pad during 2021 is highlighted in red**

Heap height increment

At the beginning of this heap leach operation, the stacking height of primary heaps was 8 m. Continuous improvements addressing aeration capacity and efficiency have led to the possibility of increasing the stacking height, and therefore the tonnage over leaching pads and leaching residence time. Currently, the heaps at the primary stage are stacked to a height of 9.5 m, which is the maximum of the stacking equipment capabilities. The stacking height increase has led to an additional 1 million-tonne ore/heap, resulting in approximately 80 days additional leaching time in the primary leaching phase.

Aeration development

Aeration of the heaps has been continuously improved since the beginning of the project. Research done in Terrafame (Arpalahti, 2019) supported the idea of adding aeration capacity in the heaps. The increased heap height led also to a new aeration concept. With the new construction method, the aeration pipelines are installed at three different heights (1, 3.5, and 6 m).

Installation

Under normal operating conditions, the aeration distribution array is constructed continuously as the stacking of the new heap progresses. Aeration lines are installed over the heap and dropped over the stacking front to three different heights set by preconstructed rest-benches. The lines are then connected to the main aeration lines and fed by blowers located at both sides of the heaps. Stacking resumes and the lines are effectively buried within the heap.

The aeration capacity can be adjusted at mainline level for each blower. In addition, the air flow can be further trimmed for each individual air line, by operating the single-line valves located at the connection to mainline. This makes it possible to operate the air supply with extreme precision, improving air supply efficiency, heap temperature control, work safety, and ergonomics.

In a different scenario, some heaps have all their blowers located on one side of the heap (instead of blowing air from both sides). In this case, Terrafame has been testing a modified design for aeration supply. This different model ensures that about 16% of the total air blown to the heap is directed straight to the opposite side, bypassing the proximal end of the heap. This different approach minimizes the risks of reduced air supply to the far end of the heap (furthest from the source of air), if there are any air pressure drops over time. This conceptual model is presented in Figure 3.

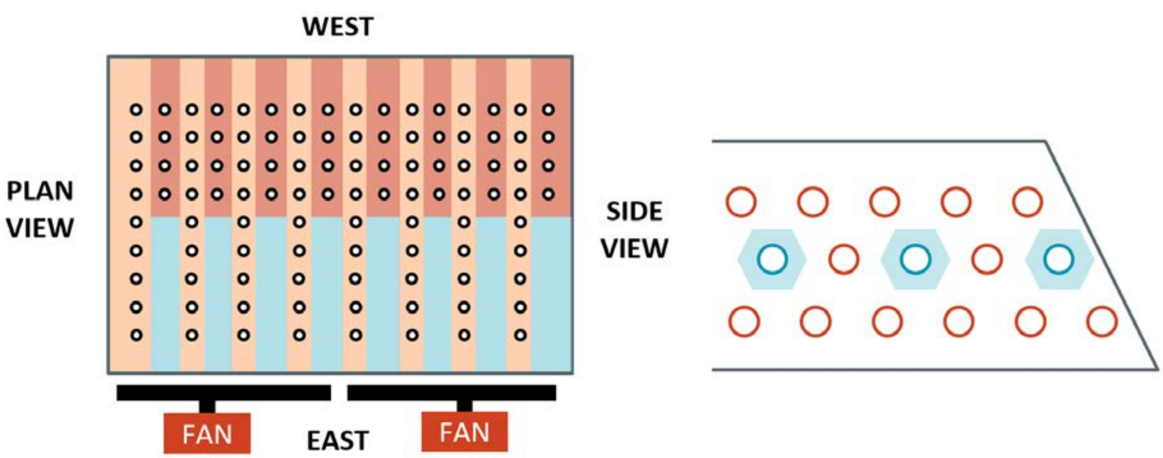

Figure 3: Special case, heap with all blowers on one side of the heap, different aeration setup, where part of the air lines supply air straight to the western half of the heap

Extra air

Over the last four years, Terrafame has focused on boosting aeration capacities for each primary heap. Whereas the aeration supply network (Figure 4) is currently close to an optimal level in terms of cost-efficiency, it has been identified as a developmental potential, with the increase in absolute air volumes blown within the heaps.

As of now and in the past, increasing aeration capacity in the primary heaps has been one of the contributors to enhanced leaching performance and acceleration of yield gains. The additional air volume fed into the heaps is seen to accelerate the leaching reactions, and increase heat formation and evaporation. The aeration capacity achieved for the primary heaps as of 2022 is +100% of the original capacity.

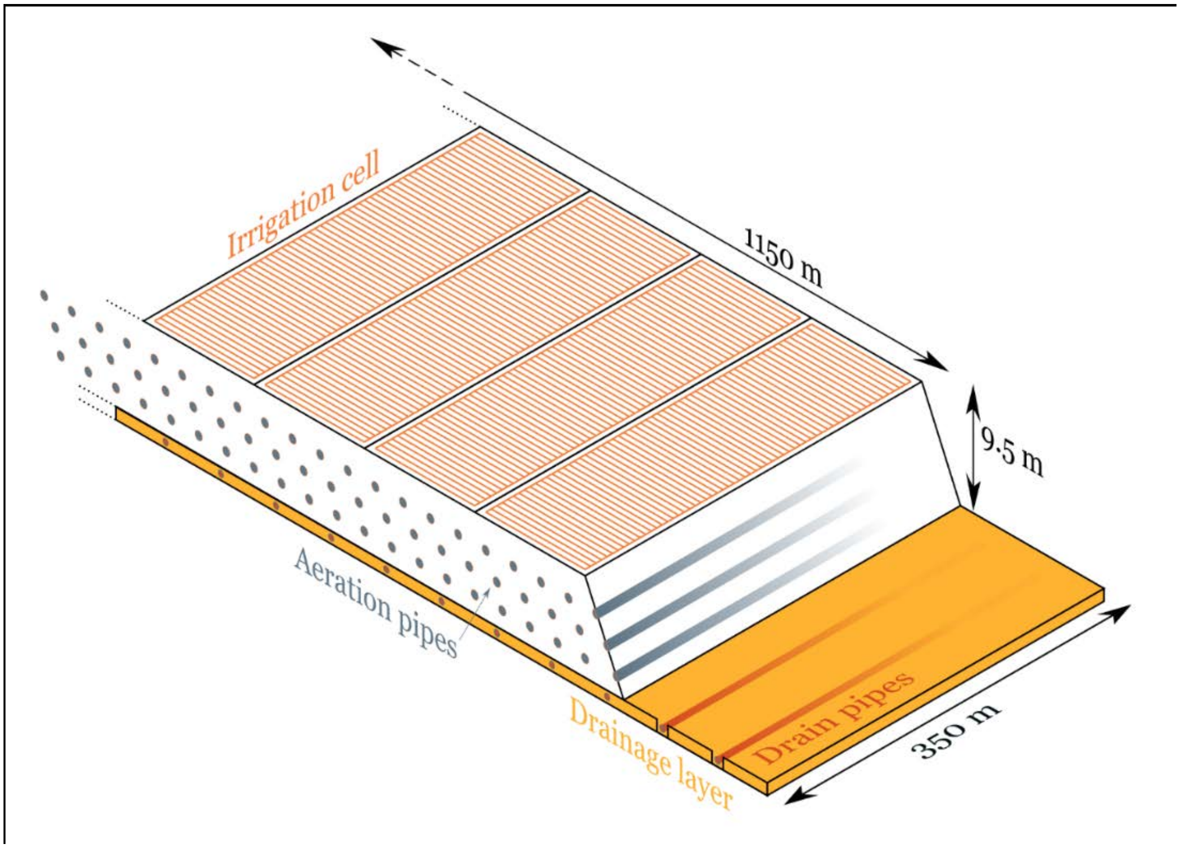

Figure 4: Primary heap installation concept, depicting irrigation cells, aeration lines, and drainage layer

Secondary leaching

Secondary heaps, pad 1

Secondary heaps pad 1 has been in use as a multi-lift heap leach operation since 2010. The secondary leaching stage hosts partially leached ore reclaimed from the primary heap leaching pad after the primary leaching stage ends. The rate of stacking at the secondary leaching pad is linked to the mine-to-heap production rate. Secondary heaps pad 1 contains four separate secondary heaps. Heaps 1 and 2 have already stacked to the level of five lifts, while heaps 3 and 4 contain four and three lifts, respectively.

The current life-of-pad plan aims to achieve nine lifts for secondary heaps pad 1 (Figure 5), which achieves the maximum height permitted by the regional environmental authorities. Progressive reduction of the top of the heap surface, irrigation pumping capabilities, or geotechnical stability of pad have not been deemed to be limiting factors for the number of lifts to be constructed at secondary heaps pad 1.

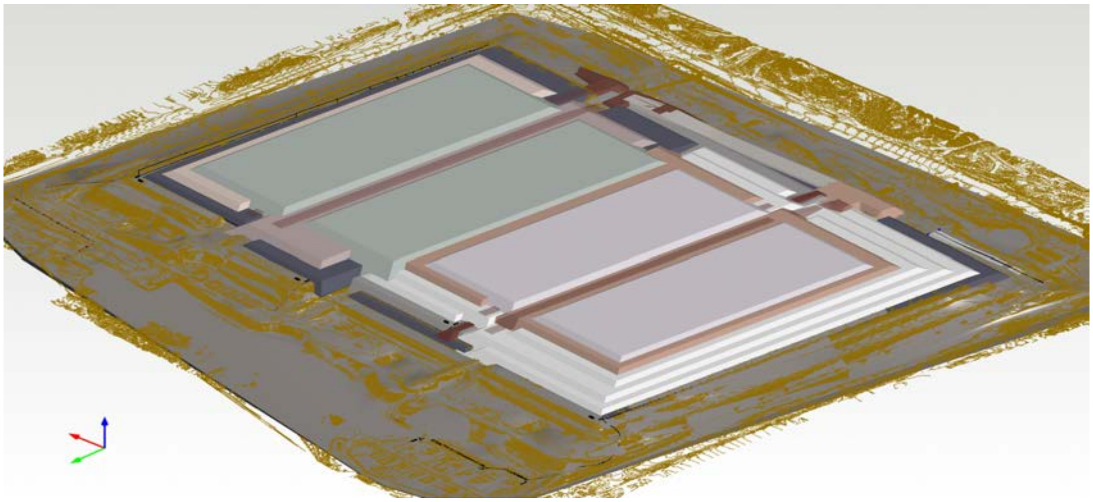

Figure 5: Life-of-pad stacking plan

Secondary heaps, pad 2

Since 2019, Terrafame has been actively designing the future secondary heaps pad 2. This second area expands Terrafame's secondary leaching stage and will be of comparable size to secondary heaps pad 1 (Figure 6). Differences in logistics and operability between both secondary leaching areas are caused by process and technology developments achieved during this last decade.

Construction of the new secondary heaps pad 2 starts during 2022. The new pad is expected to be commissioned for production during 2026, when the stacking of the first heap and first lift will start.

Figure 6: Planned location for secondary heaps pad 2

Stability of multi-lift leaching pads

Geotechnical stability control and monitoring of the multi-lift heap environment have attracted increased attention at Terrafame for the last two years. As of now, there is no evidence of imminent stability risks. The different failure mechanisms inherent to a multi-lift structure, and observed world-wide in comparable operations, have been understood by Terrafame, but not yet observed. Internal and external partners agree that a solid stability monitoring program and in-house expertise buildup are necessary, as Terrafame's multi-lift pads grow in height.

Besides daily field inspections, our means for monitoring multi-lift heap movements are currently focused on medium-term deformations, and the method used is Interferometric Synthetic Aperture Radar analyses (InSAR and derivate interpretations). This method evaluates differences in satellite-bound radar imagery with a visitation frequency of every six days. The method works well during the warmer half of the year, and millimetric movements can be identified if the movement persists in time or accelerates.

During the winter months the coherence of radar data is reduced significantly, which limits the ability to monitor the heap stability with InSAR. To improve reflectivity and data coherence over the winter months, Terrafame is currently installing physical corner reflectors at several key locations. This will improve the consistency of InSAR analysis, as well as reactivity if a continuous lift movement develops.

Challenges

As an integral part of any operation of this scale and complexity, there are inherent challenges with different natures and origins, which must be addressed organically. Terrafame is no different in that regard, and expert and production teams work towards improving process and cost efficiency. In this section, we present two examples of operational challenges that the company addresses continuously.

Gypsum

Calcium-containing minerals are leached and the production of gypsum is continuous. Gypsum precipitation in the irrigation pipeline is significant, and the leaching operation demands intensive monitoring and maintenance of the irrigation equipment. Each year the consumption of the irrigation dripline is around 40 million km. The development of crushing and washing processes for the used driplines started in year 2018, and currently most of the dripline (~70%) is recycled.

Clogging is also observed in the whole solution circulation equipment, including pumps and valves. Research and development work is ongoing to resolve the challenges of both process and maintenance operations.

Water balance

As described by Arpalahti (2016), the mine is located in a region where the yearly rainfall/evaporation is net positive. However, the continuous production enables good processing conditions in the heap leaching, which generates enough heat to evaporate the extra water. The annual change in the precipitation amount significantly affects the mine solution balance. In 2016–2018, the solution balance was negative, enabling the company to decrease the volume of stored solutions in the area. In the years 2019–2021 the balance has been positive, forcing the company to use extra capacity in the solution purification processes. During recent years, about 8 million m^3 of purified water has been released annually into nature. Water management is currently well organized, and the amount of contaminated water in the area is considerably less than in earlier years.

Battery chemicals

Terrafame decided to invest in a battery chemicals plant in 2018. Construction started in 2020 and the facilities were ready in June 2021.

Nickel and ammonium sulfate production started in August 2021, and cobalt sulfate production in February 2022.

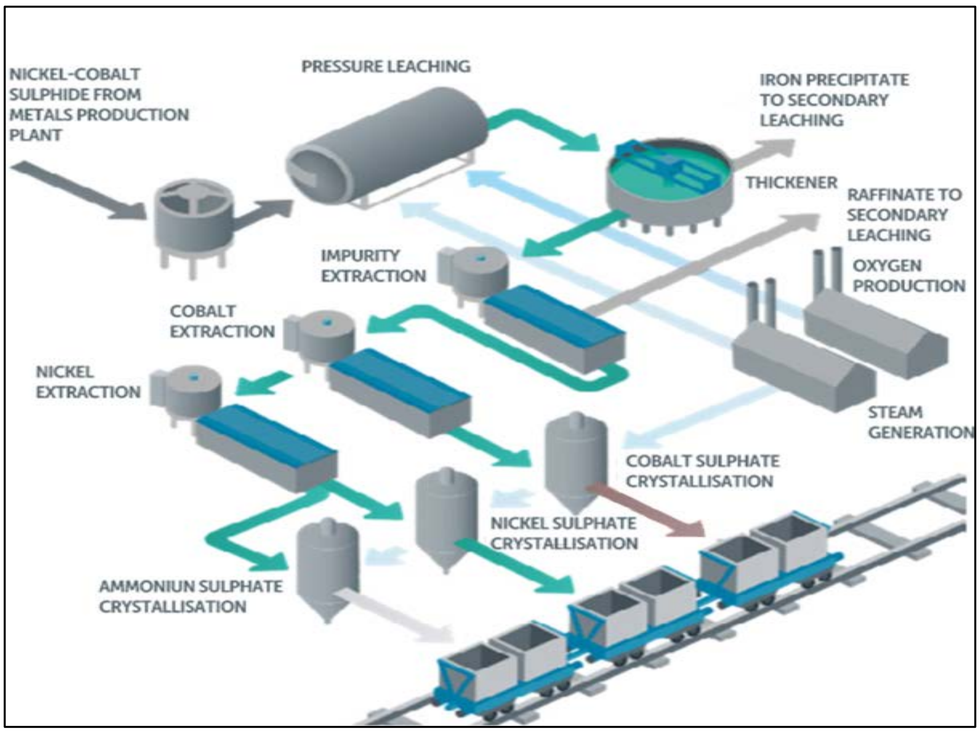

Figure 7: Battery chemicals process

The production capacity of nickel sulfate in the spring of 2022 was approximately 25% of the maximum capacity. Ramp-up of the production to the targeted capacity of $NiSO_4$ 170,000 tonnes per year and $CoSO_4$ 7,400 tonnes per year is ongoing.

Uranium recovery

A uranium plant was built in 2011 by the previous owner of the mine. The plant has not started operating yet. However, equipment checking, updating, and planning for start-up is ongoing, and the start-up schedule will be set up in 2022.

Production statistics

Production of metals in 2021 remained at the same level as in the three previous years. Nickel production was 28,582 (28,740) tonnes, representing a decrease of 0.6% year-on-year. Zinc production was 54,353 (55,100) tonnes, which was a decrease of 1.4% year-on-year. The production ramp-up of the battery chemicals plant began in June 2021.

In 2021, net sales of the battery chemicals business were EUR 27.1 million and net sales of the metal intermediates business were EUR 351.3 million. In 2020, total net sales came from the metal intermediates business.

Conclusions

Since taking over the operation of Talvivaara mine in 2015, Terrafame has continuously increased the production volumes of both nickel and zinc. Currently, production is close to the planned capacity. The building of a battery chemicals plant to produce chemicals for the continuously growing electric car industry has been successful, and the production ramp-up is ongoing. Simultaneously with the successful operation ramp-up, excess water at the mine site has decreased from approximately 10 million m^3 to 3 million m^3. This is because it has been possible to pump large quantities of water from, for example, the open mine pit to the bioleaching process, in order to make up for some of the liquid volume evaporated from the heaps. Between 2016 and 2018, evaporation from the bioleaching pads was higher than precipitation from rain or snowfall, producing a negative water balance. Continuous process development is essential, as the enhanced bioleaching process has also caused new operational challenges, such as gypsum precipitation.

In the near future, Terrafame plans to increase the primary leaching residence time to enhance the leaching process and improve the efficient use of the mine's mineral reserves by recovering natural uranium from the mine's process solution. The mine has been granted permission to start operating an extraction-based uranium recovery plant. An investment decision on the plant will be made in 2022.

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