History of Metallurgy in Finland: The Outokumpu Story

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Introduction
The small, peaceful country of Finland, "Suomi" to the 5 million Finnish people, has had a turbulent history. It has been able, however, to produce the famous chemist Johan Gadolin (1760-1852), the famous composer Jean Sibelius (1865-1957), and a large number of distinguished metallurgists.

Until 100 AD the territory of Finland was sparsely inhabited by the Lapps, a nomadic tribe of Mongolian origin. Between 100 and 800 AD, two new peoples arrived, one from the southern shores of the Gulf of Finland, the other, called the Saame people, from the Ural. These forced the Lapps to retreat to the north. From the eleventh century onward, the Swedes began to invade Finland and finally drove the Finns back from the western and southern coasts, where they themselves settled (Fig. 1). During the Napoleonic Wars, Russia seized Finland and in 1809 it became a Grand Duchy of the Russian Empire.

During the Swedish rule, Turku (called Åbo in Swedish) was the capital of Finland, and Swedish was the official language. During the Russian domination, the capital was moved to Helsinki (Helsingfors in Swedish) in 1812, and Finnish became the official language in 1863. However, under Nicholas II, in 1900 the Russian language was imposed; later the autonomy status was dissolved, and the country suffered from repression. With German help, a secret liberation force was formed during World War I. After the collapse of the tsarist regime in Russia and widespread turmoil, Finland declared its independence on November 15, 1917. Finland had its own civil war in 1918 between those who supported the Russian troops in Finland and those who favoured close relations with Germany. There was a project to invite a German prince to become a king of Finland but the project was abandoned and a republic was installed when Germany lost the war.

At the beginning of World War II, the Soviets occupied parts of Finland. These, however, were regained a few years later with German help when Finland entered the war as an ally of Germany in 1941. When the Germans were defeated Finland had to yield the territory she had regained, together with the Petsamo Peninsula (Fig. 2), and to pay a high war indemnity amounting to nearly half of the country's annual income.

At present, the country has two official languages: 93.6% of Finns speak Finnish as a mother tongue and some 6% are Swedish-speaking. A western democracy, Finland elects a president every six years. The feudal system never existed in Finland, and agriculture has throughout the ages been almost entirely in the hands of independent peasant proprietors. The majority of Finns belong to the Lutheran Church. The Finnish language has been traced to a region beyond the Ural Mountains in Russia. Finnish belongs to the Finno-Ugric language group along with Hungarian. The Estonian language is its closest relative.

First Mineral Discovery
In the wooded hills of eastern Finland, a place called Outokumpu which can be translated as "mysterious" or "strange hill" and refers to a real hill which local legends
claimed held hidden wealth. As early as 1725, local prospectors sent samples of the minerals they had found to the College of Mines in Falun, Sweden, for analysis. Their hopes were disappointed; the samples were iron pyrite, not gold.

In 1908, a huge metallic boulder was discovered 65 km southeast of Outokumpu. Tests showed it was mostly chalcopyrite and had presumably been dragged from its source in the Outokumpu region by ice sheets during the last ice Age. Test drilling conducted in 1910 at the “mysterious hill” indicated the existence of a large copper ore deposit that would ultimately form the basis of the company’s activities for decades. Construction of the mine and a smaller smelter began. Outokumpu’s first shipment,
60 t of copper ingots, was sold in St. Petersburg in June 1914. Operation at this original mine, which was expanded to include the Kereti area next to it, only ended in 1989. Today the town of Outokumpu which grew up with the company has about 9400 inhabitants and a few of the company’s subsidiaries.

**A Mining and Metallurgical Enterprise**

In 1918, a young mining engineer, Dr. Eero Mäkinen (Fig. 3) who had recently graduated from the Technical University in Stockholm, joined the company. As its president and leader for decades until his death, he was to have a tremendous impact on Outokumpu’s development. Without his vision and persistence, the struggling company would have failed on several occasions. In 1924, when private capital was lacking in Finland, and foreign interests threatened to take over, Dr. Mäkinen strongly advocated that the Finnish State assume ownership of Outokumpu. This took place in December of the same year; the same time that major copper deposits were discovered in Chile.

Outokumpu’s growth coincided with Finland’s rapid industrialization in the late 1920s and early 1930s. The country moved from an agrarian economy and a strong dependence on forest products to become an industrial society based on modern technology. An important driving force in this industrial expansion was the rapid development of hydroelectric power plants, first at Imatra and then on all the major rivers. From the beginning, Finnish industry enjoyed the advantage of cheap and abundant electrical energy. New mining technologies developed to take advantage of electrification, and electrometallurgical refining processes were adopted to replace earlier smelting methods that required coal or petroleum.

Production of copper semi-products began in Porit in 1940. The flash smelting process was developed at Harjavalta in the late 1940s. In 1950, the company also established its metallurgical laboratory which developed through the years to become Outokumpu Research Oy, an excellent research facility. In 1951, an exploration department was established to look for new ore deposits.

**The Imatra Copper Smelter**

The first small copper smelter was shut down in 1929 and Outokumpu became a major supplier of flotation concentrates to foreign refineries. Plans moved ahead under Mäkinen’s direction for the construction of a new large smelter. In 1935, the company constructed what was then the world's largest electric copper smelter (Figs. 4 and 5) in Imatra on Finland’s eastern border with Russia in Viborg Province (half way between Helsinki and Saint Petersburg). The concentrate analyzed (dry) 23% Cu, 36% Fe, 36% S, and 4% SiO₂. The charge to the furnace was 43% to 48% concentrate (with 6% H₂O), 37% to 31% partially roasted concentrate with 9% H₂O (dry analysis: 26% Cu, 37% Fe, 4% S, and 5% SiO₂), 13% to 16% quartz, and 7% to 6% limestone.

The Norwegian-built furnace had an annual production capacity of 12 000 t of blister copper. With cheap power readily available from the new Imatra hydroelectric generating station, electrification of the plant was total; even steam needed for secondary processes and heating came from an electric boiler, avoiding the high cost of fossil fuels or the need to burn wood from already overcut forests. The planners of the smelter decided to include a process to extract sulphur dioxide from the smelter gases and store it in liquefied form for transportation in railway tank cars to pulp mills and chemical industries where it was in demand. The Imatra sulphur dioxide recovery facility was to be the world's largest, with an annual production rate of 16 000 t.

On January 12, 1936, the first batch of newly smelted copper was poured from the
Imatra furnace, but getting the sulphur dioxide recovery plant on stream proved more of a challenge. It took nearly a year before the plant was in operation. Production goals were lowered, but economical operation remained elusive. The venture cost the new company dearly, even though it yielded valuable experience. The Outokumpu engineers were learning by doing what had never been done before.

In 1939, Russian forces invaded the Karelian District very near the new plant. When World War II erupted in Europe, and the German armies moved into the Soviet Union, Finland allied itself with Germany in the hope of reclaiming its lost territories. Once again, Russian troops were thrown against Finnish defence forces on the eastern frontier. In June 1944, the threat of Soviet invasion forced the removal of the smelter from the war zone to Harjavanta on the west coast to protect Finland’s only source of copper. It was completely dismantled and rebuilt at the new site within six months, just before the Russians occupied the Karelian District and took over one fourth of Finland’s hydroelectric power.

Nickel

In the years following the discovery and development of the massive Outokumpu orebody, the most significant find by Finnish prospectors was a major nickel deposit in the Petsamo region, almost on the Arctic Ocean. The sheer difficulty and expense of mining this remote resource kept it from being developed until war in Europe created an urgent demand for the metal, essential in the production of high-strength steels and in alloys used in electrical and marine components.

In 1934 the Petsamo find was leased to Inco, the International Nickel Company of Canada, and its subsidiary, the English Mond Nickel Company. At first it was planned to build a railway to Linahammar on the Arctic Ocean and from there the ore would be transported to Canada for smelting. At the end of 1937, however, supported by experience gained at Imatra, it was decided to build an electric furnace-plant at Kolosjoki in the immediate vicinity of the mine. The plant would be located 90 km north of the Paatsjoki hydroelectric power station project. Plans were drawn by Inco engineers in association with the Birmingham Electric Furnace Company and Elektromekanik in Oslo who would supply the Söderberg electrodes. The Winter War forced cancellation of the project when Russian troops invaded the eastern border of Finland.

The Soviet Union, aware of a major metal resource on its northern frontier, issued a demand for permission to operate the mine or to establish a joint Finnish-Soviet nickel production company. Although the British lease-holders had given up any expectation of completing the mine and putting it into production, the British government wanted to forestall the likelihood of Finnish nickel being put to use in the German war industry, and raised no objection to the Soviet proposal. The German’s need for nickel was urgent; they wanted crushed ore shipped to their plant immediately, and when smelting facilities were in operation at Petsamo, they expected to be supplied with nickel-copper matte ready for refining.

An agreement between I.G. Farben* and the newly-founded Finnish company Petsamo Nikkeli Oy was signed on July 23, 1940. Shortly after, it was announced that Germany would lend 10 million Finnish marks to the Finns for construction of the Petsamo plant. Plans were to smelt the ore at Imatra, then complete the refining in the electrolytic plant at Pori. Shipment of the first raw material reached Imatra in the spring of 1941, but when war broke out anew in the summer, deliveries stopped. Imatra was near enough to the eastern frontier to become caught up in the fighting and was put out of action until the end of the year. Nickel ore production resumed the following summer. Finland’s entry into the war as an ally of Germany resulted almost immediately in the commitment of Petsamo’s entire output to I.G. Farben.

In June 1942, the power station at Paatsjoki was on stream, a month later smelting of nickel concentrate started, and in January 1943, the matte produced was purified in Peirce-Smith converters (blown with air to remove iron). In September 1944, operations stopped because of the war. During this period 300 000 t of nickel-copper ore

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*Full name is Interessengemeinschaft für Farbenindustrie; the German Chemical State monopoly during the Nazi regime.
were smelted and 16 500 t of white metal (NiS_{2}-CuS) were produced, with a nickel content of 9530 t, and a copper content of 4840 t. Figure 6 shows the electric furnaces used.

With the collapse of Germany, Finland suffered the loss of Karelia and the cession of Petsamo, which became known by the Russian name Pechenga, to the Soviets, reducing Finland’s nickel supply to the output of the small Nivala mine. The new nickel smelter at Kolosjoki, now partially destroyed, was taken by the Russians. It was rebuilt and supplied with electricity from Murmansk.

Originally, the ore containing about 3.5% Ni, 1.5% Cu, 25% Fe, and 13% S was charged directly to the electric furnaces. At present, a flotation step became necessary; the sulphide concentrate containing, in addition to nickel, 1.5% Cu, 3.5% Fe, and 23.5% S, is roasted to oxide and reduction melted to anode metal for electrolytic refining at Monchegeorsk in Russia. Smelting is conducted in three electric furnaces with a total capacity of about 1800 t of concentrate per day. Each furnace is supplied 22 000 kV.A at an operating voltage of 350 volts. The electric furnace matte is blown for iron removal in horizontal side-blown converters, and the converter product is subjected to slow cooling and matte flotation.

Nickel re-entered the picture in Finland with the discovery of the nickel-bearing pyrrhotite ore deposit at Kotalahi in 1954. The company’s engineers succeeded in applying the flash smelting and electrowinning method to nickel production, and construction of the Harjavalla nickel plant was completed in 1960. The ore mined at that time analyzed 0.8% Ni and 0.3% Cu.

**Zinc**

Zinc became Outokumpu’s second most important metal with the opening of the Vihanti mine in 1954. In time, Vihanti was supplanted by the Pyhälinsi mine, whose complex ore also yielded pyrite. In the early years, some of the company’s biggest customers were Finnish pulp mills, who burned the ore to yield sulphur dioxide needed for bleaching wood pulp. Pyrite concentrate was also sold for production of sulphuric acid and fertilizer.

**Cobalt**

Next, a cobalt plant was built. Cobaltiferous pyrite from the Outokumpu mine proved an important source of this strategic metal, making Outokumpu the only major European producer of cobalt. In the late 1960s, metallic cobalt production was terminated and the plant was transformed into nickel and cobalt chemicals production.
an automatic dosing equipment from bins into the collecting conveyor, from which the charge is carried by a conveyor to the feed bin of a rotary kiln 55 m long and 2.8 m in diameter. In the kiln the charge is heated to a temperature of 1000°C to 1100°C with the CO gas obtained from the smelting furnace. This saves about 1000 kWh of electric energy per ton of ferrochrome produced. The preheated charge falls into the mixing drum, where the charge can still be altered, and passes then into the six feed bins of the smelting furnace.

From the feed bins the charge passes in a continuous flow through feed tubes into the smelting furnace. The maximum effect of the electric furnace with its three Söderberg electrodes is 24 000 kV.A. The slag that is left on the surface of the molten ferrochrome in the ladle is poured into the granulation launder and the ferrochrome is cast into pieces of 80 mm by 100 mm by 150 mm. Ferrochrome can also be cast into ingots of about two tonnes, which, after cooling, are crushed and screened, mainly to pieces of 10 mm to 150 mm.

Sulphur

Flash smelting technology was harnessed to produce iron oxide, elemental sulphur, and sulphur dioxide. Waste heat was used to generate electrical power. The first unit of the Kokkola complex, on Finland’s west coast, was thus a sulphur plant, operational from 1962 until 1977, when a drop in sulphur demand and rising oil prices led to the discontinuation of production.

Flash Smelting

The patent on flash smelting was among the first of Outokumpu’s. It was filed in 1947 in Finland and eight other countries. The inventors were Petri Bryk (Fig. 7) and Johan Rysselin. Many other patents have later been filed related to the flash smelting method and related devices. These patents, protecting the invention, have made it possible for Outokumpu to sell about 40 licences for flash smelters around the world (Table 1). Today 40% of the world’s primary copper production uses Outokumpu’s flash smelting process.

The concept of flash smelting was invented as a result of the need to economize energy. Imatra’s all-electric smelter was dependent on cheap hydroelectric power. When the plant was moved to Harjavalta, alternatives had to be found to decrease the cost of smelting. In 1948, power costs represented 40% of the expense of producing copper. The logical step would be a switch to coal- or oil-fired reverberatory furnaces, but the idea was rejected because of the lack of foreign exchange to import fossil fuel.

The company’s metallurgists came up with an old idea that had never been tried on an industrial scale — autogenous smelting. The method would use the heat of oxidation of iron and copper sulphides to bring the concentrate up to the smelting temperature, saving on coal and electricity. This type of process was used in the blast furnace smelting of rich pyritic ores. John Rysselin was handed the task of designing and demonstrating a pilot smelting plant using this novel approach. His assistant was Petri Bryk, a young engineer who would later become a leader in Outokumpu’s expansion.
They went to work on a demonstration plant at Harjavalta in 1946, had it working by the following year, and presented a proposal to the board of directors for a full-scale plant using what they called "flash-smelting" technology, to be in production by 1948. Authorization for building the first flash-smelting facility was given in 1947 (Fig. 8). Successful operation was achieved in September 1949 with continuous smelting being maintained almost without electricity or fuel. By 1953 power became a mere 7% of the smelter's operating cost. The flash smelting of nickel concentrates started in 1960 at Harjavalta. The adoption of oxygen enrichment of the flash smelting process in 1971 was a decisive improvement.

The slags from the flash smelting furnace and converter require separate cleaning. The slags must be reduced to achieve a sufficiently low nickel content. Reduction is carried out in an electric furnace using coke as the reducing agent. The waste slag from the electric furnace is granulated in water and discharged. The matte containing nickel, copper, iron, cobalt and sulphur as the main components is fed to the converter together with flash furnace matte.

**Flash Converting**

Closely related to flash smelting is flash converting whereby molten matte is cooled and the solidified material is comminuted, mixed with fluxes, then oxidized in a flash furnace to get blister copper, thus by-passing the Peirce-Smith converter. Although energy is lost during cooling and energy is spent in comminution, the over-all process is said to be still more energy efficient than blowing air, or oxygen-enriched air in the converter. The concept is presently being applied on an industrial scale, and can be considered as a two-stage flash smelting operation.

**Inco's Flash Smelting**

Independently and nearly simultaneously, Inco engineers were researching the use of oxygen for the smelting of sulphides (Fig. 9). They patented an oxygen flash smelting process in Canada in 1954 which was filed in 1949; this apparently was inspired from an old U.S. Patent by Oliver Garretson in 1898. Inco’s first 500 t/d oxygen flash smelting furnace went on stream in Ontario on January 2, 1952. Inco's approach was, therefore, different from Outokumpu's. Inco was seeking energy economy by eliminating nitrogen in the air from the system, a concept that was applied later in the steel industry at Linz in Austria — the so-called LD Process. Outokumpu engineers were seeking energy economy because they were deprived of hydroelectric power as well as coal. They, therefore, sought pyrite as a source of fuel.

**Summary**

Finland presently has four metallurgical plants, in Harjavalta, Pori, Kokkola and Tornio. The Harjavalta Works started production in 1945 when the copper smelter of Outokumpu Oy was moved to Harjavalta from Imatra, where it had been operating for several years. A water power plant in the immediate neighbourhood was one of the main factors affecting the choice of the new site. The Kokkola and Tornio Works were built in the 1960s. The nickel process in Harjavalta dates from the same decade.

Harjavalta Works produces about 100 000 t of anode copper, 70 000 t of cathode copper and about 16 500 t of cathode nickel annually and is targeted for 160 000, 125 000, and 33 000 t/y, respectively, in the near future. The copper is sent for further processing to Pori Works, where nickel, silver, selenium, and gold are recovered from the impurities of the anode copper. The nickel concentrates contain on average 4% Ni, 30% S, 40% Fe, and 1% Cu. In the smelter, the nickel is made into a high-grade matte in which the nickel content is 55%. This is purified further by leaching and electrolysis into cathode nickel, 99.95% Ni. The copper concentrates contain 23% Cu, 34% S, and 30% Fe, is refined at Harjavalta to 99.5%.

Flash smelting was developed independently by Outokumpu and Inco engineers in the 1940s.

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**REFERENCES**


