ENVIRONMENTAL LOAD OF THE COPPER AND NICKEL MANUFACTURE AND THE MANAGEMENT OF ENVIRONMENTAL LOAD

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1 INTRODUCTION

Outokumpu copper plant based on electric smelting was moved from Imatra to Harjavalta in 1944 because of the World War II. After the war Finland was suffering from severe energy shortage. This shortage made the Outokumpu metallurgists and engineers resort to the theory of autogenous smelting, whereby the heat produced by oxidizing metal concentrates is used to maintain the smelting process, and turn that into commercial reality. The first copper flash smelter ever went into operation in Harjavalta in 1949. The technology has since been applied to nickel concentrates. Today, over 50 licensed factories in all five continents evidence its success producing about 50 % of the world’s primary copper and 30 % of the nickel. (Paatela 2002 and Mäkinen 2006)

The success of the flash smelting process was initially based on the low energy consumption of copper smelting. Very soon it was noted that flash smelting process off-gases are very suitable for further processing of sulphuric acid, liquid SO₂ or sulphur (Mäkinen 1999). The further evolution of copper and nickel manufacture in Harjavalta is shown in the Table 1 (Heino & Koskenkari 2004, pp. 9, Ahola 2005 and Norilsk Nickel 2007).

Table 1. The history of copper and nickel manufacture in Harjavalta (Heino & Koskenkari 2004, pp. 9, Ahola 2005 and Norilsk Nickel 2007).

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1944</td>
<td>Outokumpu copper factory is moved from Imatra to Harjavalta.</td>
</tr>
<tr>
<td>1945</td>
<td>The start-up of the Outokumpu copper factory</td>
</tr>
<tr>
<td>1947</td>
<td>The start-up of the Kemira sulfuric acid plant</td>
</tr>
<tr>
<td>1949</td>
<td>The start-up of Outokumpu copper flash smelting process</td>
</tr>
<tr>
<td>1959</td>
<td>The start-up of Outokumpu nickel flash smelting process</td>
</tr>
<tr>
<td>1960</td>
<td>Outokumpu nickel cathodes production starts</td>
</tr>
<tr>
<td>1971</td>
<td>The start-up of the oxygen plant</td>
</tr>
<tr>
<td>1995</td>
<td>The start-up of AGA hydrogen plant</td>
</tr>
<tr>
<td>1995</td>
<td>The direct Outokumpu nickel process (DON)</td>
</tr>
<tr>
<td>2000</td>
<td>American OMG buys hydrometallurgical part of Outokumpu nickel manufacture</td>
</tr>
<tr>
<td>2002</td>
<td>OMG Harjavalta Nickel Oy starts the nickel chemical production</td>
</tr>
<tr>
<td>2004</td>
<td>Swedish New Boliden buys the Outokumpu copper and nickel smelters</td>
</tr>
<tr>
<td>2007</td>
<td>Russian Norilsk Nickel byes OMG Harjavalta Nickel Oy</td>
</tr>
<tr>
<td>2009</td>
<td>Norilsk Nickel begins to use of Talvivaara mine nickel concentrate</td>
</tr>
</tbody>
</table>

Copper and nickel flash smelters developed by Outokumpu form the heart of the Harjavalta industrial park, which can be seen in Figure 1 (Boliden Harjavalta Oy 2012). In the 300 hectares area act over 1000 employees. In the area is acting also over 100 seasonal subcontractors (Heino & Koskenkari 2005, s. 15).
Figure 1. The companies in Harjavalta industrial park (Boliden Harjavalta Oy 2012).

Earlier Harjavalta conquered the world with the aid of Outokumpu flash smelting process. Ever since the end of the nineteenth century the world has come to Harjavalta, when many foreign process engineering and energy companies (AGA and Boliden from Sweden, OMG from United States of America, Norilsk Nickel from Russia and YARA from Norway) decided to invest in Harjavalta industrial ecopark.

In spite of process engineering and energy companies in Harjavalta industrial ecopark are also acting seven companies in the areas of maintenance, internal transport, process planning and projects, industrial sanitation, guarding, and restaurant activities (Ahola 2005, Leinonen et al. 2007 and Heino 2008).
2 COMPANIES IN SYMBIOSIS WITH COPPER AND NICKEL FLASH SMELTERS

Flash smelting is a pyro metallurgical process for smelting copper sulphide concentrates as well as nickel sulphide concentrates (Figure 2). Besides the main elements, copper, sulphur and iron, the concentrate includes also smaller amounts of different heavy metals (Ni, Zn, Pb, Co, As, Sb, Bi, Ag, Au, Pt and Pd). Thus sulphide ore is very problematic, but on the other hand there are more possibilities to utilize the energy content and different elements of the concentrate. (Luomala 2002)

In the manufacturing process fine dry copper sulphide concentrates and quartz sand as flux are blown into a reaction shaft with industrial oxygen enriched air. The products are a Cu-Fe-S matte, SO$_2$ enriched off-gases, and a slag. The matte is further processed in Peirce-Smith converter to obtain the metallic copper. Heating needed for smelting is generated in the exothermic reactions of oxidizing the Fe and S in the feed. The iron oxide reacts with the quartz forming fayalite slag (Luomala 2002).
Blister copper from PS-converter is refined in the anode furnace and cast into anodes. Then anodes are then transported to Pori to copper electrolysis unit. The slag from flash furnace and converters are treated in the different concentration unit to recover the residual copper. The recovered copper is recycled back to the flash smelting furnace and also to PS-converter. The slag mill tailings are pumped to the tailing area nearby. The clarified water from the tailing pond is recirculated to be used as process water. The copper flash smelting process involves several by-product and dust removal stages as illustrated in Figure 3. (Riekkola-Vanhanen 1999a)

Figure 3. Flowsheet of the Boliden Harjavalta Oy copper manufacture, by-product recovery and dust removal processes (Riekkola-Vanhanen 1999a).
The DON nickel flash smelting method is illustrated in Figure 5 of chapter 2.1. The process is similar to the copper procedure with the exceptions that the converting stage has been eliminated and slag enrichment system is based on reduction in electric furnace. High-grade matte is produced using the flash smelting furnace and electric furnace. The slag from the electric furnace is granulated and partly utilized. The DON nickel flash smelting process involves several by-product and dust removal stages as illustrated in Figure 4. (Riekkola-Vanhanen 1999b)

Figure 4. Flowsheet of the Boliden Harjavalta Oy DON process, by-product recovery and dust removal processes (Riekkola-Vanhanen 1999b). (The abbreviations used are: DON = direct Outokumpu nickel flash smelting, FSF = flash smelting furnace, EF = electric furnace, ESP = electrostatic precipitator, WHB = waste heat boiler)

The SO$_2$ from copper and nickel production lines recovered and treated to make either liquid SO$_2$ or H$_2$SO$_4$ is introduced in Figure 5. The main reactions of sulphuric acid manufacture are (Heino 2002a):

\[
SO_2 + 0,5 O_2 \leftrightarrow SO_3 \quad \Delta H^\circ = -99,0 \text{ kJ/mol} \quad (1)
\]

\[
SO_3(g) + H_2O(l) \leftrightarrow H_2SO_4(l) \quad \Delta H^\circ = -132,5 \text{ kJ/mol} \quad (2)
\]
2.1 Norilsk Nickel Harjavalta Oy

The nickel production hydrometallurgical process flow sheet is shown in Figure 6 (Latvakokko 2008). The high-grade matte from nickel flash smelting process is leached in atmospheric leaching and the matte from electric furnace is leached in the other leaching line. The Talvivaara mine nickel sulphide concentrate is charged directly to FSF leaching line. (Latvakokko 2008, Pääkkönen & Mattelmäki 1996 and Heino 2002b)

Copper, iron and cobalt are separated from the solution, and the remaining nickel solution is treated to produce nickel powder and briquettes by hydrogen reduction and cathode nickel by electro winning. Other important products are different nickel salt solutions. Cobalt sulphate solution is transported to OMG Cobalt factory to Kokkola and ammonium sulphate is produced as a by-product. (Pääkkönen & Mattelmäki 1996 and Heino 2002b)
2.2 Suomen Teollisuuden Energiapalvelut STEP Oy Harjavalta unit

Suomen Teollisuuden Energiapalvelut Oy (STEP) utilizes the extra heat of the copper and nickel flash smelting processes. The energy is captured by WHB shown in Figure 2. A similar kind recovery boiler is also in the nickel production line. The reaction heat formed in the sulphuric acid plant (Figure 5) through the reactions 1 and 2 is exploited also by STEP (Heino 2002a).

The products of STEP are process steam, high temperature steam, process energy, district heating energy, raw water, salt-free and precipitated water, electric energy, and compressed air (Heino & Koskenkari 2004).

2.3 Oy AGA Ab Harjavalta Unit

Oy Aga Ab Harjavalta unit manufactures oxygen, nitrogen and argon by air distillation. The hydrogen is made from industrial gasoline. The oxygen, nitrogen, argon and hydrogen are used mostly in manufacturing of copper and nickel in Boliden Harjavalta Oy and Norilsk Nickel Harjavalta.
2.4 YARA and Kemira Oyj Harjavalta units

The main product of Kemira Harjavalta unit is aluminium sulphate made from sulphuric acid and aluminium hydrate \((\text{Al(OH)}_3)\). The agency of the sulphuric acid and liquid sulphur dioxide is also Kemira’s business. Further, Kemira manufactures urea phosphate, different granulated and glasshouse fertilizers. (Heino & Koskenkari 2004, pp. 25)

3 GRADUAL DEVELOPMENT OF SYSTEM DIVERSITY AND ENVIRONMENT

In Table 2 is shown the product and company diversity progress in Harjavalta industrial area between the years 1945 - 2010.

Table 2. The product and company diversity progress 1945 - 2012 (Heino et al. 2006, Leinonen et al. 2009 and Heino 2010).

<table>
<thead>
<tr>
<th>YEAR</th>
<th>COMPANY</th>
<th>PRODUCTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1945</td>
<td>Outokumpu</td>
<td>Anode copper</td>
</tr>
<tr>
<td>2012</td>
<td>Boliden Harjavalta Oy</td>
<td>Anode copper, nickel matte, sulphuric acid, and sulphur dioxide in smelters of Harjavalta plant. Cathode copper, gold, silver, platinum and palladium concentrate, copper sulphate, nickel sulphate, copper telluride, and selenium in electrolysis of Pori plant</td>
</tr>
<tr>
<td></td>
<td>Norilsk Nickel Harjavalta Oy</td>
<td>Nickel cathodes, nickel briquettes, nickel powders, nickel fine powder, nickel solutions, nickel chemicals, ammonium sulphate, copper sulphide, and cobalt sulphate solution</td>
</tr>
<tr>
<td></td>
<td>SP Minerals Oy</td>
<td>Screened granulated nickel slag for sand blasting and roofing felt production</td>
</tr>
<tr>
<td></td>
<td>Kemira Oyj</td>
<td>Aluminium sulphate</td>
</tr>
<tr>
<td></td>
<td>YARA</td>
<td>Urea phosphate, different kinds of fertilizers, urea</td>
</tr>
<tr>
<td></td>
<td>AGA</td>
<td>Gaseous oxygen, hydrogen and nitrogen, liquid oxygen, nitrogen, and argon</td>
</tr>
<tr>
<td></td>
<td>STEP Oy</td>
<td>Process steam, high temperature steam, process energy, district heating energy, raw water, salt-free and precipitated water, electric energy, and compressed air</td>
</tr>
</tbody>
</table>
The decrease of the sulphur dioxide emissions in Harjavalta due to recovering and its further processing has been huge. In 1950 specific sulphur emissions were 1152 kg per ton of produced copper and nickel metal. In year 2011 the specific sulphur emission was only 15 kg per ton of produced copper and nickel metal. Because of the efficient sulphur dioxide recovery the emissions from Harjavalta copper and nickel smelters are among the lowest in the world shown in Figure 7 (Mäkinen & Taskinen 2006). (Boliden Harjavalta Oy 2012)

![Figure 7. SO₂ emissions from various Cu (Dotted bar) and Ni (Blue bar) smelters (kg SO₂/tonnes Cu or Ni) (Mäkinen & Taskinen 2006).](image)

Meanwhile it has also been quite a remarkable decrease in heavy metal emissions. Total dust emissions in 1985 were 1100 tons and in 2011 6.8 tons. The recovery and recycling of dusts have an important effect on the environment, because dusts contain quite a lot of heavy metals. (Boliden Harjavalta Oy 2012)

In spite of additional energy recovery through reactions 1 and 2 in chapter 2.2 and diversified sulphur based product manufacture illustrated in Figure 8 the capture of the sulphur dioxide and dusts has significant influence on the environment (Heino & Koskenkari 2005). The forest death area around Harjavalta smelter is less than 1 km². Mostly it has formed in the early days of the copper production. A broad heavy metal polluted area is situated in Russia in the Kola Peninsula where the area of forest death is about 600 -
1000 km². Another area is found from Sudbury, Canada, where mining and smelting activities have created 170 km² of barren land. (Kilkkilä 2003)

Figure 8. The utilization chain of sulphur (Heino & Koskenkari 2005).

The main and biggest problem is the utilisation of copper slag (Heino 2006). There has been long time in progress research work to find out and remove substances, which can prevent reuse of slags from copper and nickel flash melting processes. The yearly accumulation of copper slag is about half million tonnes. The land filled copper slag residuals are classified as a hazardous waste because of excessive dissolution of heavy metals (arsenic and antimony among other things). Slags fine grain size after flotation complicates also its future utilization. Dumping or disposal of such huge quantities of slag cause environmental and space problems. (Leinonen 2006)

The favourable physico-mechanical properties of copper slag can be utilised to make the products like cement, fill, ballast, abrasive, aggregate, roofing granules, glass, etc. (Gorai et al. 2002 and Kiviö 2006). The totally different slag handling process is needed to manufacture above products.

According to Leinonen et al. (2009) 45 000 tonnes/a of the granulated nickel slag is utilised in sand blasting and roofing felt industries by SP Minerals and about 125 000 ton-
nes/a are still dumped in landfills. At the moment the main obstacles to a wider utilisation of granulated nickel slag are the environmental properties of slag and fluctuations in its composition, which lead to changes in the slag's stability.

Despite the obstacles, there are possibilities to promote slag utilisation and one very promising way is to use nickel slag in a drainage layer of a tailings cover of Boliden industrial dumping area near the nickel plant factory decreasing the transports costs and environmental impacts (Päivärinta 2007). Both environmental and economic advantages will be significant radically improving both economy and ecology releasing needed area to other more valuable purposes.

Also iron precipitate (about 30 000 tonnes/a) and calcium precipitate from hydrometallurgical part of nickel manufacture and dregs (1 580 tonnes/a) from sulphuric acid manufacture are also landfilled near the factory area (Norilsk Nickel Oy 2012 and Virolainen et al. 2011).

The issue of utilising low grade heat for use in other schemes such as in new district heating arrangements also needs to be looked at. Other ways of utilising low grade energy sources also need to be investigated therefore such as the effective utilization of waste heat and energy from industrial processes so as to facilitate chemical reactions, phase transitions and unit operations required for the treatment of waste streams.

4 INTERACTION BETWEEN DIFFERENT COMPANIES AND CITY OF HARJAVALTA

One of the most important features of Harjavalta industrial park is the utilization and cascading the energy captured from copper and nickel flash smelting processes and from sulphuric acid manufacture. The energy and material exchange between the companies is shown in Figure 9. (Heino & Koskenkari 2004)
Figure 9. The material and energy change between the companies in the Harjavalta industrial park (Heino & Koskenkari 2004 and Heino 2010).
5 CONCLUSIONS

The most important local and regional advantages of Boliden copper and nickel production in symbiosis with other companies in Harjavalta industrial ecosystem are:

- Positive environmental progress because of the better raw material efficiency,
- Better product diversity because of the company diversity progress,
- Utilization and cascading the energy captured from copper and nickel flash smelting process and from sulphuric acid manufacture,
- Improved safety actions because of the co-operation between the firms adding the material and process knowledge and
- To the city of Harjavalta, the most crucial benefits of the industrial area are employment, international dimension, intellectual capital and imago of the famous firms.

The diversified use of raw materials and material residues has following advantages:
- Reduce the use of primary natural resources,
- Stay under the limit of excessive use of non-renewable materials and
- Improve our approach to addressing the global environmental issue of sustainability.


