

## Cobalt and nickel – the pick of the bunch

The use of cobalt compounds dates back to antiquity. The Greeks, Romans, Egyptians and Babylonians valued cobalt compounds because, even in small amounts, they were capable of giving glass a blue color that couldn't be matched.

The miners of the Middle Ages were less interested in cobalt. In fact, the appearance of cobalt minerals was important to them only in that it indicated that far more valuable elements like copper, silver or tin were present. However, when medieval smelting methods failed to produce useful metal from cobalt minerals, the miners held that underground goblins, in German the Kobolden, had tried to fool them. The Latin name cobaltum was created from this German name. Cobalt metal was first described by the Swedish chemist Brandt in 1735.

Pure cobalt is similar in appearance to iron, but it is harder and more resistant than steel. The metal, which has a density of 8.9g/cm<sup>3</sup>, melts at 1,495° C. By comparison, references in scientific literature on its boiling point vary substantially, ranging from 2,900° to 3,200° C.

At normal temperatures cobalt metal is stable in air or when exposed to water. It first burns to oxide at white heat. In contact with diluted acids, especially nitric acid, cobalt metal is relatively reactive. On the other hand, concentrated nitric acid has a passivating effect because of oxide formation.

Cobalt almost always occurs in association with nickel in nature. The most important minerals are cobaltite or cobalt glance (cobalt sulfarsenide), skutterudite or smaltine (cobalt arsenide) and erythrite (cobalt arsenate). Large deposits are found in Canada, Zaire, Zambia, Finland, Morocco and Russia. Unlike cobalt, nickel was recognized as a utility metal 4,000 years ago in ancient China, where it was used in the form of an alloy similar to nickel silver. Coins made of a nickel alloy were in circulation in ancient Greece.

The name nickel also stems from miners' language. When they stumbled onto a reddish ore in Saxony's Annaberg some 300 years ago, the miners thought they had discovered copper. They soon realized their mistake and subsequently called their find "copper nickel."

Nickel was the name of a notorious mountain demon, and the double name indicated that the copper had been bewitched by the demon. When the Swedish chemist Cronstedt studied the mineral, he discovered the new metal, and he chose to adopt the folkloric name.

Pure nickel is a silvery metal that can be polished, forged and rolled like iron. The pure metal melts at 1,453° C and begins to boil at 2,732° C. Its density is nearly identical to that of cobalt. In compact form nickel is highly resistant to air and water. As a very finely dispersed powder, it is self-combustible in air (pyrophoric nickel). Mineral acids corrode nickel metal relatively easily.

With a share in the earth's crust of only 0.015 percent, nickel ranks 22nd in the frequency scale of elements. However, its share in the total weight of the earth is estimated at three percent, since the earth's core probably contains some 160 trillion (!) tons of the metal in the form of an iron-nickel alloy. Nickel is also abundant in the cosmos. Iron meteorites contain an average of eight to nine percent of the metal.

On the earth's surface, nickel is almost always bound with sulfur, silicic acid, arsenic or antimony. The most well-known nickel minerals are garnierite (basic nickel-magnesium silicate), pentlandite, laterite (oxidic ferronickel ore), ullmannite (antimonial nickel) and the coppered nickel arsenide (NiAs), which was the one that deceived the miners in the Middle Ages. The largest nickel deposits are in New Caledonia, Canada, Cuba and Russia.

Cobalt and nickel are also important as trace elements. On average, the human body contains two milligrams of cobalt; 50 milligrams are taken in with our daily food. In areas where cobalt is rare, deficiencies have been observed in cattle. An important nutritional aspect is cobalt's role as a central atom in vitamin B 12 .

An average of some 10 milligrams of nickel circulates in the body fluids of an adult, whose daily intake should be about 0.1 milligrams. Little is known of nickel's biological function, but it seems to contribute to the metabolism of carbohydrates. Some people are known to experience allergic skin reactions to the nickel used in costume jewelry.

### **Cobalt production in Goslar**

In the 18th and 19th centuries, cobalt compounds were mainly used in Germany for blue dyestuffs production. But when Gebr. Borchers began its activities in the field of cobalt chemistry around 1900, the company had no intention of trying to compete with the well-established government-owned factories in Saxony, which produced blue dyestuffs at low cost from raw materials mined in their own Erz Mountains.

The ambition of the chemists in Goslar was spurred by completely new areas of application, especially the use of cobalt as an alloying element. The first high-speed tool steel was developed from ferrocobalt alloys with chromium, molybdenum or tungsten as fluxes. In just a short time, this special steel became a top choice in cutting tool materials.

One particular problem was the search for a suitable raw material to use for metal recovery, as only very limited possibilities were available at the turn of the century. The only known sources, which were used by the French, were the oxidic cobalt/nickel deposits in New Caladonia. For test purposes Gebr. Borchers had previously received asbolin, a mineral containing large amounts of iron and manganese, from this source. Subsequent attempts to isolate useful quantities of cobalt metal from this mineral did not offer satisfactory results.

In addition, the potential for arsenic ore had not been fully explored: the most important deposits were in Canada, Burma and North Africa. In fact the only sources exploited at that time were the native deposits in the Erz Mountains. Because of their arsenic deposits, minerals from the Harz Mountains with low nickel and cobalt content produced complex speisses during melting decomposition.

Unfortunately there were no acceptable processing methods for speiss at that time. The chemists and metallurgists at Gebr. Borchers gave up ever being able to recover pure cobalt metal from the ores of the Harz.

Unexpected assistance came from the leading ore and metal traders of London. This was due to the fact that around 1903 mining of the so-called Temiskaming ores began in the Canadian province of Ontario. This ore interested traders because it contained a relatively large amount of silver. After smelting, the English company Quirk-Barton produced a cobalt speiss, from which it removed most of the arsenic by alkaline decomposition. This cobalt speiss was reacted with sulfuric acid to a crude sulfate of cobalt, nickel and copper, which contained so much iron that the remaining amount of arsenic could be precipitated out of it as iron arsenate.

Unfortunately, this source ran dry after only four shipments of crude sulfate because the English were unsuccessful in recovering the silver. This was a lamentable loss for Gebr. Borchers because the sulfate supplied by the English turned out to be an excellent raw material from which cobalt could be recovered without the annoying "arsenic work." Thus Gebr. Borchers had no choice but to go back to concentrates from arsenic ores and the speiss offered by most of the metalworks.

Nevertheless, the effort paid off for Gebr. Borchers. Processes for the production of a pure cobalt oxide were worked out on the basis of the English crude sulfate and similar intermediates low in arsenic content. These methods were practiced well into the 1920s, and in some cases were even applied in Oker right up to modern times. Depending on the raw material and the desired product, the company worked with chloride and sulfate solutions, and also with mixed electrolytes. The washing of the alkali was performed in six steps:

- 1) separating the copper by electrolysis or cementation
- 2) freeing from residual copper, as well as zinc, tin and arsenic by sulfide precipitation
- 3) precipitating iron as Fe III with sodium chlorate plus sodium or calcium carbonate
- 4) precipitating manganese as Mn IV with soda bleaching lye
- 5) precipitating cobalt as Co III with bleaching lye and sodium carbonate
- 6) nickel separation, initially as nickel ammonium sulfate, and later as sulfate or carbonate.

During World War I, the young Magdeburger merchant Hermann C. Starck began to buy cobalt oxide, and later metal for the steel industry and thus established his first ties with the Borchers brothers of Goslar.

His direct business contact and partner was Senator Hermann Borchers. However, the whole chemical development dates back to the initiative of the creative chemist Dr. Karl Borchers, who later died from the injuries he suffered in an oxyhydrogen gas explosion at the copper electrolysis plant.

### **Processing cobalt and nickel speisses**

After it became clear that there would be no alternative to speiss processing for Gebr. Borchers, the company decided to build an arsenic smelting plant at a site west of the train station in Oker that was already equipped with siding tracks. Construction was completed in 1909. The conceptual work on the arsenic and cobalt/nickel project and the plant planning involved an early example of technology transfer in that the metallurgical institutes of the Mining Academy of Clausthal-Zellerfeld and the Technical University of Aachen made considerable contributions. Dr. Friedrich Borchers, who had just obtained his doctorate in chemistry, advanced the cause of the project with great enthusiasm.

It is not possible to explain every detail of the complex speiss process, but the main steps of its development can be described as follows. A practicable way to convert cobalt and nickel from speiss ore to a water-soluble or an acid-soluble form was a method known from analytical work: decomposition with bisulfate, a process that was used in Oker for some time. In those days the company tried to recover arsenic as sodium arsenide by alkaline roasting. But the cobalt/nickel recovery only became truly effective when enrichment of the two metals in a speiss fusion was introduced in addition to the roasting.

The speiss processing in Oker made rapid progress. During World War I Oker was already in a position to supply the Goslar facilities with cobalt and nickel crude sulfates and to sell them as metal or oxides. An interesting historical note is that the Belgians had just begun to exploit the copper reserves in the Congo at this time. The fact that this area would one day turn out to be one of the most important cobalt sources in the world was actually a stroke of luck.

Although improvisational skills may have played a role in earlier days, the construction of the arsenic and speiss metalworks took place with the most modern technology available at the time and under the supervision of the local authority enforcing industrial regulations. Highest priority was given to a thorough dust collection of the highly toxic arsenic. Nearly all available technologies were put to use in this project.

Collecting emissions in a dust chamber or in the so called “fox” was necessary, as was tube filtering or electrostatic flue gas cleaning, a new technology that had been introduced by Lurgi only shortly before. The towering structure that belonged to this unit was to characterize the silhouette of the plant for many years. These investments brought quick results: the measurable arsenic residues were extremely low and were far below those of comparable lead or zinc smelting plants. The construction of the arsenic and speiss smelting plants was completed in the 1920s. After the plant in the old part of Goslar was shut down, a makeshift cobalt salt facility was set up near the speiss smelting plant in 1926. Construction of a modern chemical, oxide and metallurgical plant, referred to in the company as the “met” for metallurgical, was delayed because of the world economic crisis, but eventually went on stream in 1934.

Such pioneering achievements should not obscure the fact that the world economic crisis left its mark on Gebr. Borchers AG, which had become a public company in 1923. The drop in prices of some important products had such severe effects that the family company saw its economic existence threatened. These circumstances also affected the cobalt activities, which had been expanded with such optimistic expectations.

The company’s crisis was mainly triggered by a longterm contract for Canadian cobalt ore. Due to the decline in prices, the cobalt-containing ore was supplied at a price that was substantially higher than that of the product itself. Financing such a loss-generating business was too much, even for the most obliging of banks. In retrospect it was actually a major stroke of luck for Gebr. Borchers that the block of shares held by the Hildesheim bank was acquired by a man with international experience in ore trading: Hermann C. Starck.

### **The days of the armament economy**

Around 1935 and during the Second World War , there were few opportunities to import foreign speiss and ore. The era of improvisation was born, documented by the fact that the company had to rely on the Mansfeld furnace pigs as ersatz raw materials for cobalt and nickel.

In processing these furnace pigs, the metals cobalt, nickel and copper were enriched as sulfides in the so-called black sludge, which was first roasted to promote sulfuration and then leached. With the help of iron scrap, copper was cemented out of this mixture in cementation drums. The resulting impure cobalt, nickel and iron solution was fed into the alkali flow of the “met” at a rate of some two to three tons per month. Less economical but nevertheless of historical significance for the chemical industry, the later German Democratic Republic would use this “poor man’s” raw material to cover its entire requirements for the powder production of cobalt and nickel.

### **The production of cobalt metal during the war years**

In a report to the military government published in 1946, Goslar's exact cobalt production figures were specified for the first time ever. The switch from lumpy to metallurgical grades is also documented by these figures.

Production in Goslar in the range of three tons per month is what the Allies registered in 1945. It is said that the Allies were quite surprised to find such a modern and intact plant in which cobalt metal powders were produced via oxalate and with the help of hydrogen reduction.

### **The cobalt and nickel business in postwar years**

Immediately after the fall of the Third Reich, speiss processing was resumed at a surprising pace under the auspices of the military government. A higher demand for effective crop protection products and the need for extensive control of epidemics in the regions affected by war were decisive for this move. This area of business stood its ground in the 1950s, but later lost its significance.

In the case of alloying metals, there was a temporary boom in the mid 1950s, which was primarily triggered by the Korean crisis. Unlike previous years, large quantities of high-quality ores and speisses from Canada, Morocco, the then Rhodesia and Burma were suddenly available. Long-term supplies of raw materials for cobalt and nickel recovery came particularly from the ore reserves in Burma. Besides offering economically useful amounts of copper, the speiss produced still more high-quality metals. Perspectives like these prompted H.C. Starck to expand significantly existing facilities for roasting and speiss processing, and to install a new autoclave station, as well as a copper electrolysis unit.

However, one peculiarity of the Burmese speiss had its consequences: since the ore showed a very high nickel content (the ratio of cobalt to nickel was 1:5), a perfect cobalt/nickel alkali purification system had to be set up in the buildings U 21-U 24, which used to be devoted to the processing of furnace pigs. The steps of the process were crude sulfate, copper and iron precipitation, manganese precipitation, crude cobalt precipitation and pure nickel carbonate.

To remove the sulfur, this nickel carbonate was calcined with sodium carbonate to an oxide. It was then densified to pellets with the help of an organic binder, and reduced with charcoal in the crucibles of a circular furnace.

With a capacity of 40 tons of nickel metal per month, the plant broke production records. Since the metal was very high in quality, it was soon very popular with the alloying industry, and for many applications was preferred over the purer and more expensive carbonyl or electrolyte nickel.

Cobalt recovery from the Burmese speiss was never particularly successful. This was mainly due to the fact that cobalt metal was never able to be precipitated with a low nickel content because of the large surplus of nickel. When the use of arsenic crop protection products was banned by German law at the beginning of the 1960s, speiss processing at H.C. Starck in Goslar came to a standstill. It was also the end of the era in which the company was still able to compete successfully against the large international producers with alloying metals like cobalt and nickel.

### **Coping with various types of the raw materials**

When processing of Burmese speiss was discontinued, the metallurgical installations for melting, roasting and electrolysis were virtually shut down, except for those processing some remaining speiss from German metalworks.

On the positive side was the fact that the chemical facilities in the metallurgical plant, the “met,” and in K 130, plus the nickel facilities in U 21-U 24, were suitable for the use of cobalt and nickel alkalis from intermediates that did not contain arsenic. However, charges of up to 15 tons of cobalt per month and 40 tons of nickel per month were problematic.

Especially in the case of nickel it was highly questionable whether relatively small production quantities of alloying metal would be marketable, in light of the more effective international competition after the war. Moreover, these competitors offered pure metals from raw materials that were not inferior quality.

After shutting down the speiss processing, a unique situation resulted for activities in the cobalt and nickel sectors. On the one hand, the usual raw material could no longer be processed. And on the other hand, the right products for the newly emerging markets were not yet introduced.

The cobalt metal situation was not quite so precarious, since the company could rely on a wide range of experience in processing different raw materials, intermediates and scrap. Powder was generally produced from these starting materials – a market that had enjoyed a positive development up to that point. The main supplier at that time was Duisberger Kupferhütte, a copper smelting company.

Consumption of metal powder resulted from, among other things, the increasing demand from the expanding magnet industry. Together with Phibro, H.C. Starck had an agency in the United States that supplied customers with cobalt metal.

Other starting materials were the residues from a number of Fischer-Tropsch catalysts, which were, however, usually only temporarily available. These catalysts had been used during the war and thereafter in the liquefaction of coal. Other sources for processing were cobalt residues from BASF’s so-called high-pressure carbonyl process and magnet scrap, such as the aluminum nickel cobalt types.

There were similar “ersatz” raw materials for nickel, such as nickel crude sulfates from copper electrolysis. All kinds of catalysts, ranging from residues resulting from the hardening of fats to the very valuable Raney nickel types, completed the choice of starting materials.

### **The revival of the raw material business**

From the beginning, good international connections gave the company a “back door” for acquiring raw materials. Immediately after the end of the war, and even before the return of Hermann C. Starck, the employees were able to intensify contacts with the United States. Thus as early as 1952 to 1954, H.C. Starck obtained access to the enormous cobalt supplies in U.S. stockpiles, although mostly in qualities that were only suitable for normal metallurgical use. One small consolation was the fact that substantial quantities of alloys, which for some reason or other had been declared scrap, could also be purchased.

And so products made their way to Goslar that no one would have thought possible in the days of the war: for example, the seawater-resistant nickel-copper alloy called “Monel” from the U.S. Navy. This hard and highly corrosion-resistant material, which plays a leading role in chemical plant construction today, had a nickel content of 65 percent.

For Goslar's copper electrolysis with its products, cement copper and nickel sulfate, "Monel" was obviously heaven sent. The work involved in this production was sometimes even quite spectacular. For example, tons of shafts from ship propellers were occasionally inserted directly into the cells as anodes for the electrolytic dissolution process.

Although this "Monel" only lasted a relatively short time, other valuable "treats" soon came to Goslar – this time from the U.S. Air Force. These supplies were in fact aeroengine blades, which, according to the opinion of the safety experts, were not allowed to be re-used to produce new blades because of the danger of material fatigue. As a result the high-quality alloy was declared scrap.

The analysis of a material classified as S 816 showed the following revealing results: 40 percent cobalt, 20 percent nickel, 20 percent chromium, 2-3 percent iron, 3-4 percent tungsten and molybdenum, and 2-3 percent niobium and tantalum. In other words, as far as the contents were concerned, the alloy was perfect for H.C.Starck.

However, one restrictive aspect was the fact that alloys which were developed to resist hot-gas corrosion also put up a resistance to conventional cobalt/nickel technologies. For example chromium in the chemical decomposition phase was a particularly difficult problem. In fact this metal still causes metallurgists a number of problems today.

In the meantime there were a number of high-temperature alloys based on cobalt and nickel, including stellite, hastelloy, inconel and nimonic. Over the years a number of special installations were set up at company facilities to process the available scrap as effectively as possible.

The objective of the new cobalt-nickel technology was to dissolve most metallic raw materials in suitable solvents. Tests with sulfuric acid, which was commonly used for this purpose and relatively inexpensive, were only successful in exceptional cases. For example, Monel would only dissolve with the help of an electric current. But in order to accomplish this, the metal had to be melted and cast into anodes. The bottom line was that this method was only worthwhile when the cathode reaction, for example to separate copper, can be used.

An alternative process was a reaction with nitric acid, but there was a difficulty with the nitric gases, which of course had to be concentrated. Generally speaking this was not a problem, since the appropriate installations were available in the arsenic facility. But it was soon discovered that the reaction was difficult to manage with different kinds of scrap, so it was decided to limit this variation to dissolving the pure metals in order to obtain alkali nitrate as well as alkali salts.

The third alternative was the technical hydrochloric acid used in tungsten production. However, because of the danger of an incalculable reaction, this alternative required substantial preparation to determine the dissolving behavior of each individual alloy. Most importantly, safe working conditions had to be found for the dissolving process with hot hydrochloric acid that would result in hydrogen formation without hydrogen chloride emissions. This challenge has occupied H.C. Starck up to today.

### **A special kind of solution – scrap**

Basically, all of this was nothing compared to the biggest challenge of all – how to treat the pieces of scrap that were delivered in parts ranging from a few hundred grams to several hundred kilograms. The so-called “scrap dissolver” was developed at H.C. Starck especially for this purpose. The secret behind this technology was a 10-meter high dissolving tower that stood on a heavy perforated plate. It was coated with rubber and could be filled from the top with pieces of scrap. The acid was pumped into the tower for circulation with the help of graphite heat exchangers on the outside. The connection to the atmosphere led through a graphite reflux condenser. The development of this unique scrap dissolver would not have been possible without the assistance of the former “Harzer Achsenwerke GmbH” in Bornum, now called “Harzer Apparatewerke GmbH,” the company which supplied the suitable rubbercoating and graphite lining.

Over the years several thousand tons of cobalt and nickel have been separated in these dissolvers, which are still in use today. More than anything else, the chemical facilities were able to profit from this highly concentrated solution that contained certain amounts of valuable materials. Charges of more than 500 tons of metal per year were not unusual. These scrap dissolvers were a part of the reconstruction of the “met” to allow for the processing of alloyed scrap. This was completed in 1958. In addition to the special dissolvers, there were major precipitation facilities on the ground floor and larger filter press platforms on the first and second floors. The filter press platforms were kept under a wooden roof construction with copper nails because of the danger of corrosion. The general introduction of hydrochloric acid as a solvent was underlined by the clear shift of electrolysis from sulfate to chloride, and a substantial increase of chloride in the waste water, which was considered completely harmless in those days.

### **Managing the chromium problem**

As already briefly mentioned above, the chromium found in the scrap materials provided by the U.S. Air Force was a particularly difficult obstacle to overcome. A solution to the problem was found, or at least improvised, in the chemical cobalt/nickel plant.

As was known from laboratory tests, at a pH value of 4-5, chromium together with trivalent iron can be completely precipitated as chromium III. The only problem was that the resulting chromium sludge, which was very voluminous, contained up to 20 percent cobalt and nickel. Even the most intensive washing process, in which enormous amounts of water and subsequent filtration with the otherwise well-proven filter press are required, did not provide a solution.

When the wet chromium sludge caused a storage and yield problem, and thus endangered the whole project, the “met” chemists in Goslar made use of a solution that had already proved its worth with nickel hydroxide. The wet sludge was heated in a large circular tube furnace with a direct gas flame; the dried cake was then crushed; and most of the cobalt and nickel was drawn off with acid wash water. Because of the intermediate drying, the total loss of the metals in the chromium sludge was reduced to less than five percent. H.C. Starck could easily accept this amount, particularly because its competitors in the industry had apparently not yet discovered this trick.

At about this time H.C. Starck went off on a tangent in chromium chemistry. The temporarily stocked and dried chromium sludge was calcined with sodium carbonate. The relatively “thin” chromate alkali that results from this process was reduced with sulfuric acid to trivalent chromium. The resulting green oxyhydrate was dried and sold after precipitation.

Small quantities of cobalt and nickel were found in the residues of calcination and were further processed in the smelting works.

### **The influence of metallic raw materials on smelting technology**

The direct use of metallic raw materials obviously had its effects on smelting technology. Through reduction fusion it was basically possible to include oxidic and also heavier soluble residues in the dissolving process, to homogenize mixed scrap and to cast anodes for electrolytic dissolution. The only problem was that the blast furnaces of the smelting plant were not suitable for fusion.

As so often in the company's history, the problem was resolved by returning to the technology of furnace pigs processing. The smelting crew of Goslar remembered the time-tested ellipsoid furnace, a short rotary furnace lined with an alumina tamping compound that had worked well melting the furnace pigs. Obviously, the furnace could not be used right away because various improvements needed to be made. But ultimately, nearly pure nickel and cobalt metal as well as a number of other alloys with melting points around 1,500° C were fused.

As useful as it was in the early phase, this so-called Schmidt's ellipsoid furnace was soon replaced by another acquisition: a Fulmina furnace, which was fired with tar oil and lined with a tamping compound made from quartz.

Before the electric arc furnace like the one in the "Halle Süd" building in Laufenburg was developed, which was much easier to handle in large scale production, this furnace had the decisive advantage of easily managing chromium and manganese, the main problems in the cobalt/nickel washing. When the operation is performed properly, both elements can be fluxed with the help of the Fulmina furnace. By comparison, when fusing calcined nickel catalyst residues, which often contain grease, the electric furnace has the disadvantage that a lot of silicon is also reduced from the residues that are rich in silicates. Because of this, the solubility of the metal is affected in electrolysis.

### **Cobalt and nickel products**

As already mentioned, some three tons of hydrogen-reduced cobalt metal powder was produced in Goslar every month near the end of World War II. This quantity increased to 10 tons in the 1960s. Sludges from the cobalt/nickel separation in the "met" and also chloride alkalis from metal dissolution served as raw materials. However, only in the rarest of cases was a chemical purity of the powder achieved that was comparable to the one claimed by a Belgian competitor. The Belgian company produced their powder from electrolytic cobalt from Katanga, a province in Zaire now called Shaba. As a starting material, this cobalt was much easier to process because it was extremely low in nickel.

### **Metals acquire dubious reputation**

Under the supervision of the chemist Peter Borchers, attempts were made to improve the quality of the powder in the late 1960s and early 1970s.

Peter Borchers, the son of Dr. Friedrich Borchers, is a direct descendant of Dr. Johann Christoph Borchers, who founded the company in 1807. After his studies in chemistry, he began working as the assistant to Dr. Hermann Lang, the Plant Manager in Goslar at that time. Borchers was appointed Plant Manager in Goslar when Dr. Lang died in 1964. When the company was reorganized in 1982, Borchers became head of the Research and Development Department. A number of innovations in engineering and in chemical processing took place at H.C. Starck during the career of this highly creative chemist.

When monthly production surpassed 20 tons, there was an unexpected setback for the Goslar plant: cobalt and nickel dust made headlines and were officially declared carcinogenic, at least in Germany. This meant that new permits had to be obtained from the German authorities in order to operate the existing facilities. The permits were eventually granted, but the facilities had to be completely reconstructed based on a very costly process in order to produce dust free.

Despite this threat to the very future of the binder metal cobalt and the nickel in hardmetal, producers around the world, including H.C. Starck, refused to abandon use of this metal. Major efforts were made to adapt production and working conditions to the changed regulations, especially in respect to reducing dust emissions.

### **Metal powder becomes purer and finer**

It was typical for the 1970s and 1980s that the already close producer-customer relationship in the hardmetal sector was further intensified. In close cooperation with customers – even now, a major share of the cobalt powder produced in Goslar is sold to the worldwide hardmetal industry – the purity and fineness of the powders were constantly improved over the years. These and similar advances led at the beginning of the 1980s to the development of the most well-known powder grade: it has an average grain size of 1.5 micrometers and a grain size distribution that is 99 percent smaller than five micrometer.

In addition to its use in the hardmetal sector, the application possibilities for cobalt metal powder in the diamond industry have also increased. In a typical application, synthetic diamonds with a diameter of less than 0.2 millimeters are mixed with, among other things, cobalt powder, and in some cases also with bronze, copper and tungsten powders, pressed and sintered at 900° C. The approximately 4-cm long segments can then be soldered or welded onto cutting wheels. The areas of application for such diamond tools with a metal matrix include processing natural stone, concrete and asphalt.

### **Cobalt and nickel salts**

By the 1950s H.C. Starck already had a number of cobalt and nickel compounds as intermediates in its product program. These compounds included oxalates, sulfates, carbonates, hydroxides and oxides, all of which were obtained while processing raw materials. The market soon demanded higher purity grades for these products as well, a trend that was triggered by international requirements. To fulfill the demands of the world market, processing technologies had to be improved, and quality assurance measures had to be implemented.

Investments in modern crystallization equipment were necessary to gain a foothold in the chloride business, which was particularly important for H.C. Starck. The most important investments for the company were an evaporator, a cold stirrer and screen centrifuges followed by formulation and packaging units.

These efforts soon led to success: marketable products with cobalt or nickel contents of more than 24 percent in hexahydrate were achieved without difficulty from the very pure and concentrated chloride solutions obtained from the metal dissolvers. Customers required such high-quality nickel chloride, for example, for electroplating.

One successful cobalt deal of that time deserves special mention. H.C. Starck agreed to supply on a long term basis large quantities of cobalt chloride crystals to the most important producer of adhesion promoters for steel-braced radial tires. Up to 20 tons of cobalt per month were designated for this application alone, which was kept confidential for a long time. In addition to metal powder, this order alone was enough to sustain a solid cobalt production in Goslar for years.

In the case of nickel, it was not only the sale of crystallized chloride that ensured good capacity utilization of the metal dissolution facilities in the 1970s and 1980s. A considerable share of the resulting chloride solution was required for the in-house production of carbonate, hydroxide and oxide.

It turned out to be a far more difficult task for H.C. Starck to establish itself in the very limited market sector for hydroxides. The pink-colored cobalt-II hydroxide with a 63 percent cobalt content has long been considered a particularly valuable chemical for cobalt use in oil and paint systems. The only problem is that cobalt has to be bivalent for this application. The tendency of the metal to change over to the trivalent phase in an alkaline environment can only be avoided by adding reducing agents or using other tricks. This was a problem that the Gebr. Borchers chemists also faced in former times. In the past the company therefore usually preferred to buy the hydroxide.

In the case of nickel hydroxide, which was used in batteries, there was no danger of oxidation. Gebr. Borchers developed a process for hydroxide precipitation in the 1940s. However, this method was quite complicated because the slimy precipitation product had to be dried between operations. The grade was developed for "Friemann & Wolf" for miners' lamps, whose sales were dependent on the mining operation – in other words, a declining business.

When the sales possibilities for other battery systems developed, H.C. Starck abandoned the labor-intensive, intermediate drying in cabinets for a modern multiple belt dryer. With this move the prerequisites were also created for the production of larger charges at a more reasonable cost. In addition, the company hoped to penetrate the market for pure nickel-based batteries, in lieu of the conventional mixed systems with cadmium.

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