

UDC 669.43

Development and Mastering of Extraction Processes at the Norilsk Mining and Metallurgical Complex

G. L. PASHKOV¹, I. YU. FLEITLIKH¹, A. I. KHOLKIN², K. S. LUBOSHNIKOVA¹, V. V. SERGEEV¹, A. M. KOPANEV³,
N. A. GRIGORIEVA¹ and L. K. NIKIFOROVA¹

¹*Institute of Chemistry and Chemical Technology, Siberian Branch of the Russian Academy of Sciences, Ul. K. Marksa 42, Krasnoyarsk 660049 (Russia)*

E-mail: natasha@icct.ru

²*Kurnakov Institute of General and Inorganic Chemistry (IONKh), Russian Academy of Sciences, Pr. Leninskiy 31, Moscow 117907 (Russia)*

³*Khimpolitekh OJSC, Ul. Zelenaya Gorka 1, Novosibirsk 630060 (Russia)*

Abstract

Extraction processes are considered those were developed and mastered by the authors at the Norilsk Mining and Metallurgical Complex (nowadays Norilsk Nickel OJSC) during the period from 1979 to 2009.

Key words: extraction, electrolysis, cobalt, nickel, copper, sulphuric acid

INTRODUCTION

Extraction processes are widely used in hydrometallurgical process layout for non-ferrous and rare metals though still in recent times their role in producing nickel and cobalt was insignificant. It should be considered that the works by L. M. Gindin with co-workers devoted to studies on physical and chemical laws cation-exchange extraction of metals including cobalt and nickel are pioneering ones [1, 2]. Basing on the results of these studies a method for purifying cobalt-containing solutions from impurities *via* cation-exchange extraction by monocarboxylic acids with obtaining metallic cobalt *via* electrolysis was developed and was mastered for the first time in the world at the Norilsk MMC.

The combination cation-exchange extraction and electrolysis represents the most efficient method for obtaining high purity cobalt, since impurity metals those are placed in the extraction series to the left of cobalt, can be separated *via* cation-exchange extraction, whereas the metals those are placed in this series more to the right of cobalt, can be separated at the stage of electrolysis. The extraction series of metals for C₇–C₉ monocarboxylic (fatty) acids

in the order of reducing the extraction ability looks like the following [2]: Sn⁴⁺ > Bi³⁺ > Fe³⁺ > Pb²⁺ > Al³⁺ > Cu²⁺ > Cd²⁺ > Zn²⁺ > Ni²⁺ > Co²⁺ > Mn²⁺ > Ca²⁺ > Mg²⁺ > Na⁺.

The process of purifying an aqueous solution from impurities through the extraction by cobalt soap (CoA₂) by the example of double-charged cations can be described by the equation

$$M^{2+}(\text{aq}) + \text{CoA}_2(\text{o}) \leftrightarrow \text{MA}_2(\text{o}) + \text{Co}^{2+}(\text{aq}) \quad (1)$$

Here M²⁺ = Cu²⁺, Cd²⁺, Zn²⁺, Ni²⁺; A is carboxylate ion; (aq) and (o) stand for aqueous and organic phase, respectively.

Thus, in the course of extraction, impurity metals pass into the organic phase, whereas cobalt passes into the aqueous phase. The C₇–C₉ fatty acids exhibit the following values of separation coefficients: β_{Fe/Co} ≈ 1000, β_{Cu/Co} ~ 300, β_{Cd/Co} ~ 30, β_{Zn/Co} ≈ 5, β_{Ni/Co} ≈ 1.8. In the course of a counterflow multistage process the cation-exchange extraction procedure allows readily enough separating metals similar in properties, in particular Co and Ni, which is extremely complicated under hydrolytic precipitation. The re-extraction of impurities is combined with a simultaneous regeneration of an extraction agent; it can be carried out by means of mineral acids of any type, in particular, hydrochloric acid:



As the extraction agent, for the development of technology one used synthetic C_7 – C_9 fatty acids (SFA) without dilution, and as the initial solution, that was used after dissolving commercial cobalt hydroxide (>99 %) or cobalt concentrate ($\text{Co} : \text{Ni} = 8 : 1$). The initial solution possessed the following composition, g/L: Co 130–150, Ni 15–18, Fe 3, Cu 0.3, Mn 0.5, Zn 0.01, Pb 0.01.

The technological scheme for obtaining high purity cobalt is presented in Fig. 1. All the stages of the process such as the obtaining of cobalt soap, the extraction of impurity by the cobalt soap, washing out the extract from cobalt, re-extraction of impurities were carried out in a counterflow mode. At the stages of extraction the impurity metals (Fe, Cu, Ni) passed from the aqueous phase to organic one (see eqn. (1)). The organic phase (extract) containing a considerable amount of cobalt besides

impurities was fed further for washing from cobalt. Washing was carried out by means of hydrochloric acid solutions or by means of a part of re-extract; washing waters were joined together with the initial solution and were directed to the stage of extraction. The washed organic phase was supplied for impurity re-extracting by 5–6 M HCl solution (see eqn. (2)). Re-extract (aqueous phase) was partly removed from the system, and was partly supplied for washing the extract from cobalt. The organic phase regenerated (in the H-form) was supplied to the unit of soap formation.

In total, the technological scheme involved 114 extraction steps, and an extractor of mixing sediment bowl type was used as equipment. The aqueous phase (refined product) purified from impurities after the acidifying was supplied to the stage of zinc and lead sorption. These metals form stable anionic complexes such

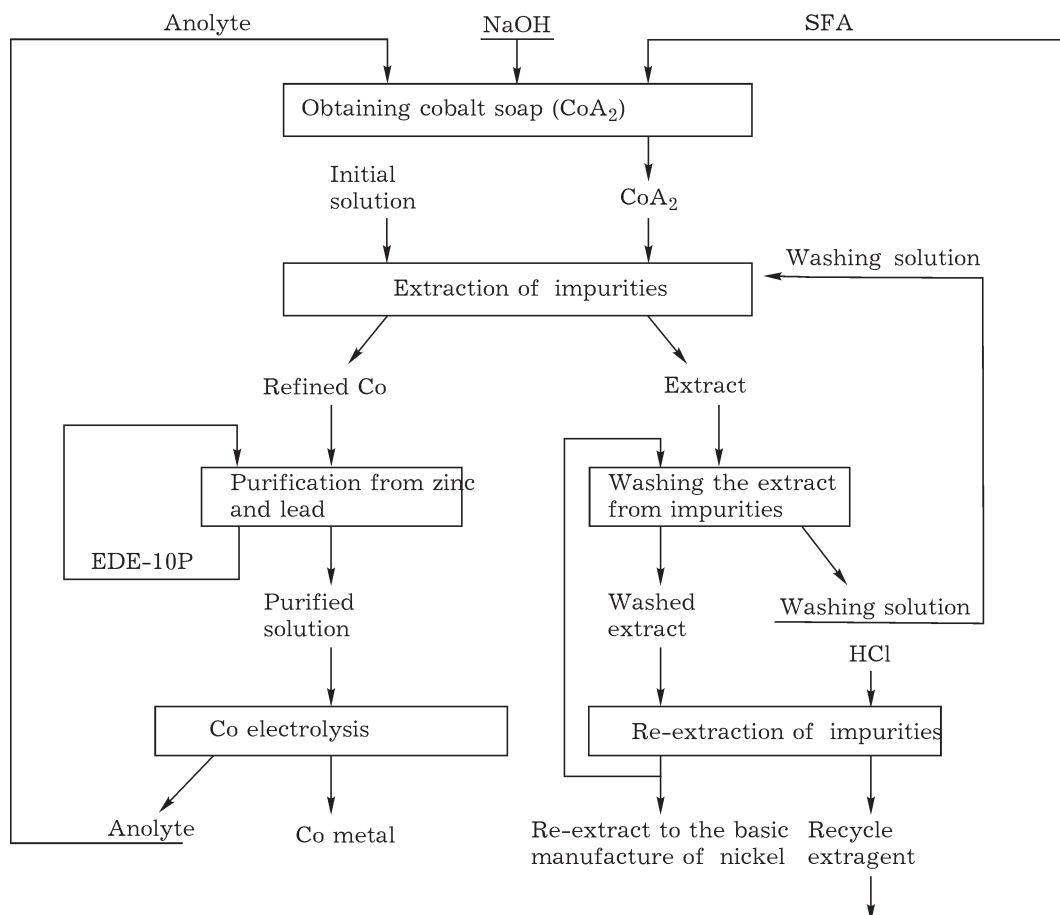


Fig. 1. Extraction electrolysis scheme for obtaining K-0 grade metal cobalt with the use of monocarboxylic acids (SFA, HIA).

as $[\text{MCl}_3]^-$ and $[\text{MCl}_4]^{2-}$, therefore the purification was carried out with the use of anion-exchange resins.

The purified solution supplied to the electrolysis exhibited the following composition, g/L: Co 130–150, Ni <0.05, Fe <0.001, Cu <0.001, Zn ~ 0.0004, Pb ~ 0.00005. The electrolysis was carried out in a bath with titanium cathodes and insoluble anodes. The current yield amounted to 90–95 %. Cobalt was partly precipitated as a cathodic deposit, whereas another part was supplied together with anolyte to the unit cobalt soap formation.

The cathodic cobalt representing the finished commodity met the requirements for top quality cobalt (K-0) and exhibited the following composition, %: Co 99.99, Ni 0.005–0.002, Fe 0.001–0.003, Cu 0.001–0.005, Zn <0.001, Pb <0.0003, Al ~ 0.001, C ~ 0.005.

A high efficiency of combining the process of cation-exchange extraction with the subsequent electrolysis, was first demonstrated for obtaining high purity cobalt, and further this was repeatedly confirmed by new extraction electrolysis technological schemes, both abroad (for example, for the extraction of copper by oxyoximes [3], that of zinc by organophosphorus acids [4]), and in Russia. In particular, we have developed novel methods for obtaining high purity cobalt with the use of the higher isoacids (HIA-1), as well as the mixtures of monocarboxylic acids with aliphatic aldioximes.

It should be noted that other studies were also carried out concerning the development of novel technological schemes with the application of extraction, including those for the Norilsk MMC those we have performed and presented in this work. This allowed researchers to involve nonconventional kinds of raw material in the processing, to obtain new kinds of production, to improve its quality, etc.

PROCESSING OF COBALT-CONTAINING SOLUTIONS

Obtaining high purity cobalt with the use of branched-chain α -monocarboxylic acids

The technology for obtaining of high purity cobalt with the use of monocarboxylic acids with normal structure for many years demonstrated the viability, however demanding for improvement. Low separation coefficients for nickel and cobalt ($\beta_{\text{Ni/Co}} \approx 1.8$) in the systems with SFA cause

a high consumption of reagents (NaOH and HCl), a plenty of steps and low productivity.

In this connection, potentialities were studied for using α -branched-chain higher isocarboxylic acids (HIA) for purifying cobalt-containing solutions from impurities [5–7]. As appeared, HIA have much higher separation coefficients for some metals, which is caused by steric effects in the formation of compounds under extraction. The most significant HIA advantage comparing to SFA consists in increased separation coefficients for nickel and cobalt ($\beta_{\text{Ni/Co}} \approx 2.3$ –3.0). As the extraction agents HIA-1 (C_5 – C_9 fraction) and HIA-2 (C_{11} – C_{19} fraction) were tested. The viscosity of HIA-1 was less than the viscosity of HIA-2 being comparable to the viscosity of C_7 – C_9 SFA; therefore further the HIA-1 fraction was used. The separation coefficient $\beta_{\text{Ni/Co}}$ for this fraction (the mixture of 2-methylcapronic, 2-methylcaprylic and 2-methyl-2-ethylcapronic acids) amounted to about 2.8, which is 1.5 times higher as compared to the values for C_7 – C_9 SFA.

Trial tests and mastering the technology with the use of HIA-1 was carried out at the chlorine-cobalt workshop (CCW) of the Norilsk MMC. The technological scheme for obtaining high purity cobalt with the use of HIA was not undergone considerable changes comparing to the scheme with the use of SFA (see Fig. 1).

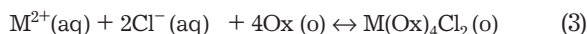
The replacement of fatty acids by HIA allowed researchers to decrease considerably the number of extraction steps in the scheme (from 114 in the system with SFA to 66 steps in the system with HIA). The consumption of alkali at the stage of soap formation and the consumption of hydrochloric acid at the stage of re-extraction are approximately 1.5 times lowered; owing to the increase in the efficiency of metal separation, the productivity of the extraction unit is 35–40 % increased. The cathodic cobalt obtained completely met the requirements for K-0 grade high purity cobalt.

Obtaining high purity cobalt with the use of monocarboxylic acid and aliphatic aldioxime mixtures

Regular studies concerning different extraction systems demonstrated that the mixtures of monocarboxylic acids and aliphatic aldioximes exhibit high separation coefficients for nickel

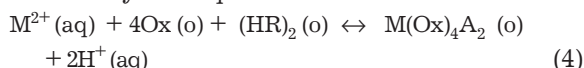
and cobalt. Aliphatic aldoximes with simple structure have general formula $R-CH-NOH$. For the studies and for developing the technology we used heptanealdoxime with linear structure [8–11]. The effect of the structure of monocarboxylic acids on the separation of nickel and cobalt is less considerable; therefore we used in the development of the technology mainly fatty acids of C_7-C_9 fraction.

The studies on the extraction of Co and Ni from chloride solutions by the mixtures of monocarboxylic acids and aliphatic aldoximes demonstrated that at $pH < 2$ Co and Ni distribution coefficients do not depend on the acidity level of the aqueous phase. Within this pH range, metals are extracted according to the coordination type:



In this case, the highest separation coefficients of metals can be realized ($\beta_{Ni/Co} \sim 100$), however, low distribution coefficients are observed for nickel ($D_{Ni} < 1$).

With growing pH the metals begin extracting according to the reactions of cation exchange, in this case the distribution coefficients for metals increase, whereas $D_{Ni} = 3-5$. The extraction process within this range can be described by the equation



Trial testing and mastering the technology, as well as earlier, were carried out at the Norilsk MMC. The main technological scheme is presented in Fig. 2.

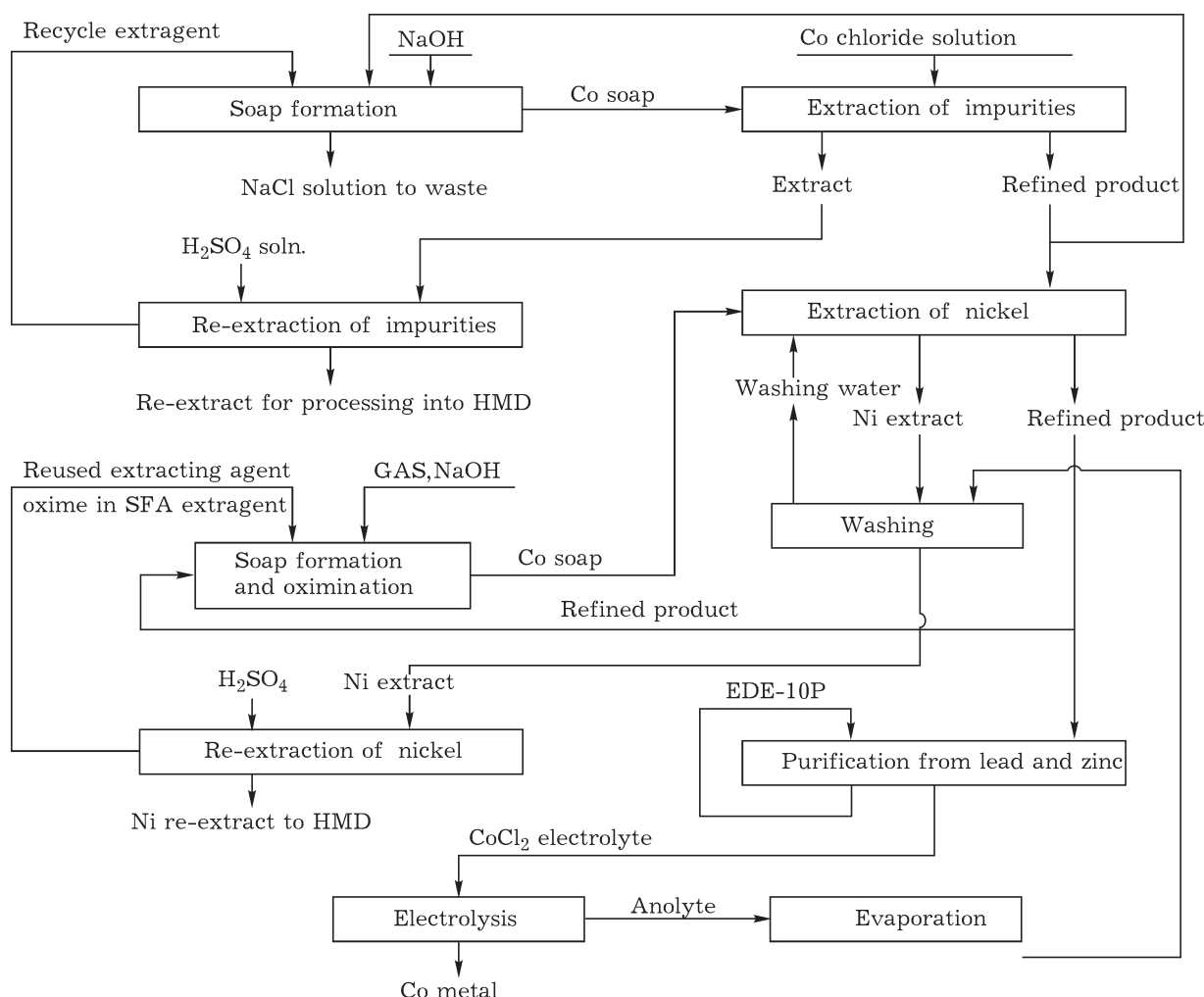


Fig. 2. Basic technological scheme for obtaining K-0 grade cobalt metal using the mixture of monocarboxylic acids and heptanealdoxime. HMD – hydrometallurgy division.

As the initial solution we used the chloride solution obtained *via* dissolving the second cobalt hydroxide. The composition of the solution was as it follows, g/L: Co 155–170, Ni 0.4–0.55, Fe 0.1–0.25, Cu 0.004–0.01, HCl 10–20. The solution was preliminary supplied to the extraction of copper and iron by SFA cobalt soap with the content of cobalt amounting to 25–30 g/L at a ratio of streams organic (o) and aqueous (aq) phases equal to 1 : 2, at 12 steps. In all the cases, the residual content of copper and iron in the refined product did not exceed 0.0004 and 0.0008 g/L, respectively. The re-extraction of impurities was carried out with the use of sulphuric acid solution (with the content of 90–100 g/L), o : aq = 2.5 : 1.

The extraction of nickel from the solutions purified from copper and iron were carried out by the solution of heptanealdoxime (1.25 mol/L) in fatty acids at 18 steps and the ratio o : aq = 1 : (1.5–2.0). The extraction agent was partly used in the cobalt form, the content of cobalt amounted to 18–20 g/L. The content of nickel in refined products varied within the range of 0.004–0.008 g/L, the content of cobalt being equal to 155–170 g/L. The refined product, just as it was done earlier, was directed to the stage of purifying zinc and lead via the sorption by resin EDE-10P being further directed to the electrolysis of cobalt. All the batches of the electrolytic cobalt obtained met the requirements for K-0 grade. The re-extraction of nickel from the organic phase was carried out by the solution of sulphuric acid with the content about 30 g/L.

It was established that as compared to the technology based on monocarboxylic acids, the productivity of the extraction unit was 1.5–2 times increased; the amount of extraction equipment units was twice reduced; the consumption of alkali and hydrochloric acid per 1 t of cobalt was by 2.5–3.0 and 2.4–2.8 t lower, respectively.

Further, as the result of additional studies, a technological scheme was developed for purifying sulphate cobalt-containing solutions of the basic cobalt manufacture at the Norilsk MMC. The scheme included the extraction of copper and iron with the use of monocarboxylic acids, the extraction of nickel by the mixtures of monocarboxylic acids and heptanealdoxime,

purifying zinc and manganese by the mixtures of monocarboxylic acids and di(2-ethylhexyl)phosphoric acid. Basing on industrial tests, regulations were developed for the reconstruction of CCW of the Norilsk MMC nickel factory concerning the extraction electrolysis technology. The realization of the technology developed instead of the precipitation technology with the use of gaseous chlorine for obtaining of flame cobalt not only could improve the quality of finished product, but also would solve the problems concerning the environment and the improvement of working conditions.

Processing of cobalt-manganese industrial products

In the processing of cobalt-containing solutions, one of complicated problems is represented by their purifying them from manganese. As a rule, the purifying is based on manganese precipitation as manganese (IV) hydrate with the use of gaseous chlorine or sodium hypochlorite as an oxidizer. In this case, a significant amount of cobalt is co-precipitated with manganese (the ratio cobalt/manganese = (3–5) : 1) in the precipitate). Further, for the extraction of cobalt and withdrawal of manganese from the operation cycle, the precipitate (manganese cake) was dissolved in dilute sulphuric acid in the presence of a reducer with the subsequent precipitation of cobalt in the form of sulphide. As the result of these operations, a significant amount of manganese comes back to the cycle, whereas as much as up to 1.0 g/L of Co remains in the waste solution, which results in a great irreversible loss of this metal.

For purifying cobalt-containing solutions from manganese we suggested a method and developed a technological scheme for extracting manganese by means of di(2-ethylhexyl) phosphoric acid (D2EHPA) and monocarboxylic acids (Fig. 3) mixture [12, 13]. We used C₇–C₉ SFA fraction. With the use of the mentioned mixtures, the separation of cobalt and manganese occurred more efficiently ($\beta_{\text{Mn/Co}} = 17–40$) than with the use of individual D2EHPA in kerosene ($\beta_{\text{Mn/Co}} = 5–10$).

According to the scheme, after the dissolution of manganese cake in hydrochloric acid,

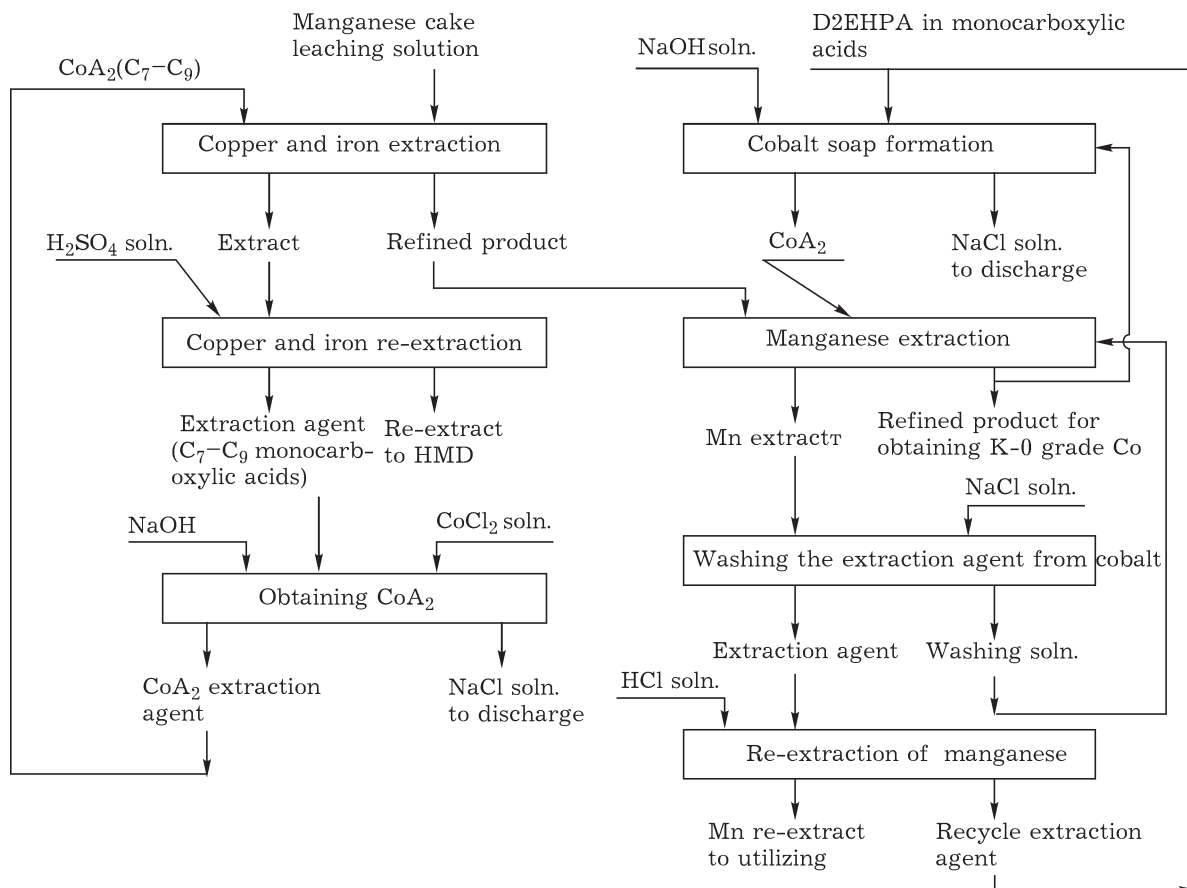


Fig. 3. Basic technological scheme for manganese cake treatment by the mixes D2EHPA and C_7 – C_9 monocarboxylic acids.

the solution of Co–Mn with the total content of cobalt and manganese amounting to 40–160 g/L (the ratio of Co / Mn = (3–60 : 1)), the content of HCl amounting to 10–15 g/L and impurities (Co, Fe) were purified from copper and iron by the cobalt soap of monocarboxylic acids. Further, the purified solution was supplied to the step of manganese extraction. The extraction of manganese was carried out by means of 30 % D2EHPA solution in SFA. Then the refined product was supplied to the stage of obtaining of K-0 grade cobalt, whereas the organic phase after washing from cobalt was directed to the re-extraction of manganese by hydrochloric acid (~5.0 mol/L). In total, 30 steps of extraction were required for the operation of purifying the solutions from manganese.

The purified cobalt-containing solution exhibited the following composition, g/L: Co 140–160, Mn <0.5, Cu <0.001, Fe <0.001. Manganese re-extract contained 130–150 g/L of Mn

and less than 2.0 g/L of Co. The extraction of cobalt according this scheme amounted to 99.5 %. The scheme developed for processing manganese cake allows one to liquidate almost completely the intrafactory turnaround of manganese, to a considerable extent decrease irreversible loss of cobalt, to a considerable extent reduce the consumption of reagents (alkalis, hydrochloric and sulphuric acids, etc.).

It should be noted that data concerning the purification of sulphate cobalt-containing solutions from manganese, obtained during trial testing, were included in the schedule of reconstructing the NMMC nickel workshop.

Obtaining high purity iron oxides from industrial products of cobalt manufacture

Iron oxides with increased purity are used for obtaining ferrites those, in turn, are wide-

ly used as magnetic materials in radio engineering, electronics, automation, etc.

The most efficient extraction agents in purifying ferriferrous solutions from impurities are presented by monocarboxylic acids (C_7 – C_9 SFA and HIA). In these systems the processes of extraction and re-extraction occur in a simple enough manner, the re-extraction of iron could be performed using dilute solutions of mineral acids, and the iron-metal impurity (Cu, Co, Ni) separation coefficients are very high amounting to about 10^2 – 10^4 [14, 15].

As the initial solution we chose the aqueous phase of Norilsk MMC iron-cobalt slurry and the solution simulating an iron-copper re-extract of purifying cobalt-containing solutions from these impurities, whereas C_7 – C_9 SFA fractions were used as the extraction agent. Basing on the laboratory research, pilot and trial tests were performed concerning the extraction of iron and obtaining iron oxides.

The initial solution was of the following composition, g/L: Fe 25–28, Cu 1.8–3.0, Co 2.5–14.0, Ni 0.32–0.98, Zn 0.5–0.6, pH 1.0–1.3. The extraction unit consisted of three iron extraction steps, three steps for washing the extract from sulphuric acid impurities and six steps of iron re-extraction by means of sulphuric acid.

In the course of testing, re-extracts of the following composition were obtained, g/L: Fe 60–80, Cu 0.0006–0.002, Co 0.0015–0.003, Ni 0.0008–0.0015, Zn 0.0009–0.00025; manganese was not found out. Iron from the re-extract was extracted in the form of goethite ($FeOOH$). The total level of iron extraction from the initial solution to the precipitate amounted to about 96.5 %. The precipitate for obtaining the product with preset dispersion composition was exposed to two-stage calcinations with quenching the calcinated material in water. In this case, hematite with particle size of 0.2–0.3 μm and the specific surface of 6–8 m^2/g was obtained.

The results of testing carried out confirmed the possibility of obtaining high purity iron oxide with the use extraction technology from the industrial products of cobalt manufacture.

PROCESSING OF NICKEL-CONTAINING SOLUTIONS

Purifying nickel manufacture sulphate wastewater from chloride ions

Nowadays the carbonate repartition filtrates of the nickel electrolysis workshop containing chloride ions are partly discharged to open territories, which results in polluting the open reservoirs by chloride ions and heavy metal (nickel, copper, cobalt) impurities.

A technological scheme for extracting chloride ions [16] was developed. A 0.5 M trialkylamine (TAA) solution in kerosene was used, with the addition of 2-ethylhexanol as the extraction agent. The technology suggested for extracting chloride ions from carbonate repartition filtrates of the Norilsk MMC nickel workshop has passed successful trial tests at the Norilsk MMC. The initial solution contained 12–18 g/L of chloride ions, 30–60 g/L of sulphate ions, and 0.005–0.0028 g/L each nickel and cobalt.

The testing demonstrated that the residual content of chloride ion in the refined product after extraction does not exceed 0.3–0.5 g/L, i.e. the purification level exceeds 95 %. The content of organic impurities in the refined product amounts to about 2.5 mg/L. The re-extraction by the solution of caustic soda resulted in obtaining re-extracts with the content of sodium chloride amounting to 200–220 g/L, the content of sulphate ion being less than 2 g/L. From the re-extracts obtained, sodium chloride is utilized via electrochemical technique with obtaining gaseous chlorine and caustic soda solutions.

The technology developed for extracting chloride ions would allow not only stopping the overflow of these solutions to open territories and preventing the latter from environmental contamination, but also stopping to use purified solutions in the system of recycling water supply at the industrial complex without any negative consequences for the process equipment.

Extraction of sulphuric acid from nickel anolyte

One of intermediate products in the processing technology for sulphide copper-nickel concentrate according to the scheme of autoclave sulphuric acid leaching in the collective Bessemer matte, developed at the MMC Norilsk Nickel including extraction electrolysis repartition of nickel-cobalt-containing solutions, represents nickel anolyte with the content of nickel and sulphuric acid amounting to 60 and

140 g/L, respectively. Nickel anolyte is formed at the stage of nickel electrochemical extraction. The most part of anolyte is further used in the operation of Bessemer matte autoclave leaching, whereas the residual part together with spent catholyte is neutralized by nickel carbonate with obtaining a nickel-containing solution supplied to the stage of nickel electrolysis. In the course of obtaining nickel carbonate, a lot of expensive soda ash is spent and salt wastewater (solutions of sodium sulphate) are formed, whose recycling requires for significant costs.

We developed a technological scheme which provides the extraction of sulphuric acid by means of 50 % trialkylphosphine oxide solution (trade mark Cyanex 923) in an aliphatic diluent (kerosene, petroleum paraffins) for removing excess amount of H_2SO_4 from nickel anolyte, whereas the re-extraction of acids is performed using water. The scheme was examined during pilot testing for the installation including five acid extraction steps, one step of washing the extract from nickel, and six steps of acid re-extraction. As the initial solution we used a solution containing 60 g/L of nickel and 140 g/L of sulphuric acid.

As demonstrated by tests carried out, the residual content of sulphuric acid in refined products amounted to 59.3–61.7 g/L (the extraction of 57.6–55.9 % into an organic phase), which is optimum for the mentioned technology, whereas the content of sulphuric acid in re-extracts ranged within 150–160 g/L.

One can see that the technology developed excludes completely any consumption of expensive soda in the process and, correspondingly, waste solutions of sodium sulphate.

The results obtained are supposed to use as initial data for technical and economic basis concerning the extraction of sulphuric acid from nickel anolyte.

Purifying nickel-containing sulphate solutions from calcium and magnesium

In the course of developing the hydrometallurgical scheme of processing Bessemer matte for purifying sulphate nickel-containing solutions from impurities, one should provide for the operation of calcium and magnesium with-

drawal from these solutions, since these impurities (especially magnesium) are accumulated in the solution to complicate the technological process. In the case when the end product is not electrolytic nickel, but its salts (nickel sulphate), the problem of isolation of these impurities becomes aggravated to a greater extent. The typical solution of nickel sulphate has the following composition, g/L: Ni 100–130, Ca ~ 0.5, Mg ~ 0.5, Na_2SO_4 50–70.

Owing to a high cost and inefficiency of such purification methods as recrystallization and precipitation, it is necessary to develop novel processes allowing efficiently extracting calcium and magnesium from solution with minimal nickel loss.

We developed the extraction technology for purifying nickel sulphate solutions from alkaline-earth elements, consisting in a successive extraction of calcium and magnesium [17, 18]. At the first stage, calcium is extracted by 0.7 M di(2-ethylhexyl)phosphoric acid solution in petroleum paraffins. At the second stage from the solution with removed calcium, magnesium is extracted by 1 M solution of di(2,4,4-trimethylpentyl)phosphinic acid (commercial name Cyanex 272), in petroleum paraffins, too. The re-extraction of calcium is carried out by hydrochloric acid, whereas the re-extraction of magnesium is performed with the use of sulphuric acid.

The technology developed allows a guaranteed purifying nickel-containing solutions from calcium and magnesium up to the residual content required (<0.1 g/L).

The data obtained are used for designing the repartition for purifying nickel sulphate solutions from calcium and magnesium.

PROCESSING OF COPPER-CONTAINING SOLUTIONS

Recycling spent copper electrolyte

During electrolytic copper refining with soluble anodes, there is an accumulation of metal impurities such as nickel, iron, arsenic, antimony *etc.* occurring in the electrolyte. At all the copper factories making cathodic copper, maintaining the electrolyte composition required is carried out via permanent withdrawing a part of electrolyte from the commodity repartition for the regeneration. For the Norilsk MMC cop-

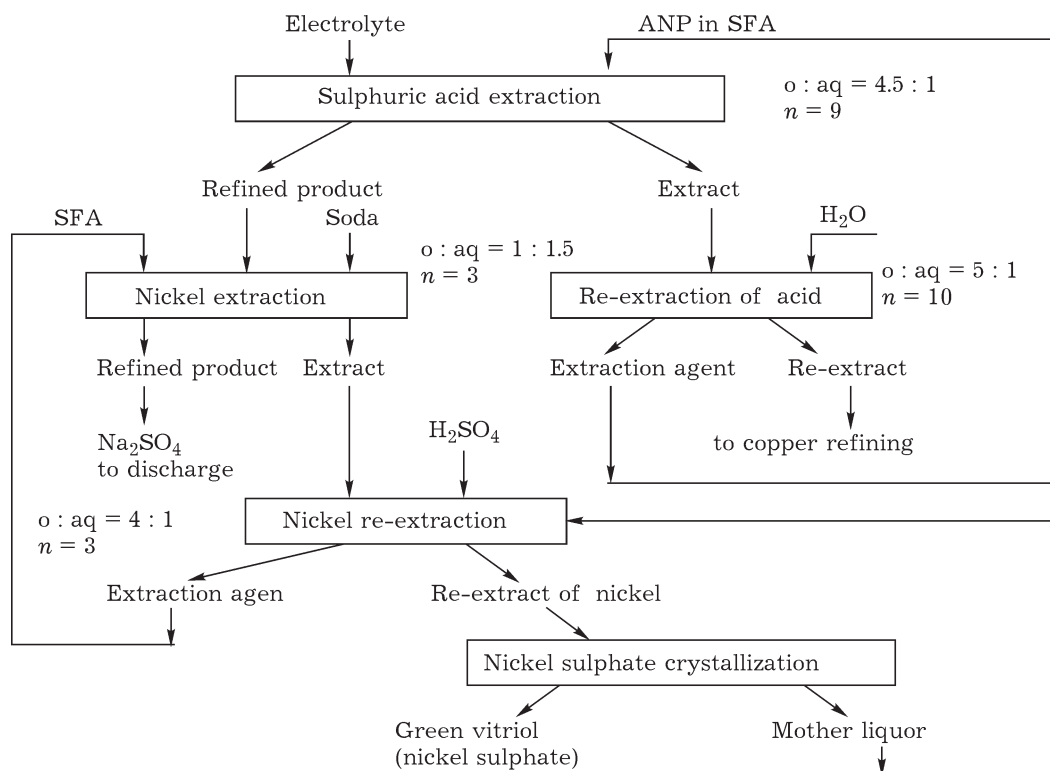


Fig. 4. Basic technological scheme for the processing of decoppered electrolyte from the copper electrolysis workshop.

per electrolysis workshop, the basic impurity is presented by nickel. The disadvantages of the technology under use based on electrolyte evaporation include a low productivity of repartition, a great loss of nickel (up to 40 %) and of sulphuric acid (up to 30 %), a high cost of equipment for the process fire evaporation.

According to the technology we developed for the extraction of sulphuric acid from spent copper electrolytes, one uses the extraction procedure with the application of binary extraction agents (Fig. 4) [19, 20]. A binary extraction agent was used based on primary amine ANP and C_7 – C_9 SFA.

Trial testing carried out at the Norilsk MMC copper workshop for the technological scheme developed demonstrated that the extraction of a sulphuric acid into a re-extract amounted to 92 %. The composition of the re-extract is as it follows, g/L: H_2SO_4 200–220, Cu 0.05–0.1, Ni 0.5–1.0, Fe 0.1, arsenic, antimony, lead <0.001. For the extraction of nickel from refined product, we used the extraction by monocarboxylic acids with re-extracting the metal by sulphuric acid solution. The

extraction of nickel into the re-extract in the course of testing amounted to 97–98 %.

CONCLUSION

The Norilsk Mining and Metallurgical Complex as the leader of Russian nonferrous metallurgy first demonstrated the efficiency of extraction in of nickel and cobalt hydrometallurgy. For the last years, creative collectives whose structure always included the experts of the industrial complex, performed a cycle of systematic investigations concerning the creation, testing and realization of rational extraction schemes including the processing of nickel manufacture commercial products, conditioning nickel and copper electrolytes, environmentally safe recycling saline industrial wastewaters, etc. The potential of these developments finally determines the prospects of extraction processes in the realization of hydrometallurgi-

cal method for processing collective Bessemer matte, calcium and magnesium withdrawal from nickel sulphate solutions, *etc.*

REFERENCES

- 1 Gindin L. M., Bobikov P. I., Kouba E. F., Kopp I. F., Rozen A. M., Ter-Oganesov N. A., Zagorskaya N. I., *Dokl. AN SSSR*, 122, 3 (1958) 445.
- 2 Gindin L. M., Bobikov P. I., Patyukov G. M., Rozen A. M., Kouba E. F., Bugaeva A. V., *Ekstraktsiya*, Gosatomizdat, Moscow, vol. 2, 1962.
- 3 McCarr G. H., *Eng. Min. J.*, 10 (1970) 79.
- 4 Cole P. M., Sole K. C., in: *Min. Proc. Extr. Metall. Rev.*, 2003. Vol. 24. P. 91.
- 5 Nikolaev A. V., Kholkin A. I., Gindin L. M., Freidlina L. Kh., Luboshnikova K. S., Kuznetsova L. M., Terentyev A. B., *Izv. SO AN SSSR. Ser. Khim. Nauk*, 5 (1972) 52.
- 6 Inventor's Certificate 753150 USSR, 1977.
- 7 Kholkin A. I., Gindin L. M., Luboshnikova K. S., Pashkov G. L., Fleitlikh I. Yu., Galantseva T. V., *Vsesoyuz. Soveshch. po Primeneniyu Ekstraktsii v Tekhnologii Neorganicheskikh Materialov* (Proceedings), Apatity, 1986, p. 47.
- 8 Inventor's Certificate 1628547 USSR, 1988.
- 9 Inventor's Certificate 1676272 USSR, 1989.
- 10 Fleitlikh I. Yu., Kholkin A. I., Sergeev V. V., Luboshnikova K. S., Pashkov G. L., Makarov I. V., Zelentsova L. V., *Tsv. Metally*, 3 (1997) 31.
- 11 Fleitlikh I. Yu., Pashkov G. L., Luboshnikova K. S., Bezrukova N. P., Kholkin A. I., Makarov I. V., Sergeev V. V., *Tsv. Metally*, 8 (2001) 51.
- 12 Inventor's Certificate 1396625 USSR, 1988.
- 13 Galantseva T. V., Tertichnaya L. A., Fleitlikh I. Yu., Luboshnikova K. S., Sergeeva V. V., Sergeev V. V., *Tsv. Metally*, 3 (1989) 44.
- 14 Kholkin A. I., Gindin L. M., Luboshnikova K. S., Mul P., Gle K., *Izv. SO AN SSSR. Ser. Khim. Nauk*, 9, 4 (1976) 82.
- 15 Kholkin A. I., Luboshnikova K. S., Fleitlikh I. Yu., Pashkov G. L., Kostrov A. V., Sergeev V. V., Galantseva T. V., Kotukhov S. B., Zelentsova L. V., Greyver M. B., *IX Vsesoyuz. Konf. po Ekstraktsii* (Proceedings), Adler, 1991, p. 26.
- 16 Sergeev V. V., Fleitlikh I. Yu., Kopanov A. M., Kalinina M. V., Pashkov G. L., Kulmukhamedov G. K., Nikiforova L. K., Kholkin A. I., Galantseva T. V., Makarov I. V., *X Vsesoyuz. Konf. po Ekstraktsii* (Proceedings), Ufa, 1994, p. 191.
- 17 RU Pat. No. 2378400, 2007.
- 18 Fleitlikh I. Yu., Pashkov G. L., Mikhnev A. D., Grigorieva N. A., Nikiforova L. K., *Izv. Vuzov. Tsv. Metallurgiya*, 1 (2008) 16.
- 19 Inventor's Certificate 1225807 USSR, 1984.
- 20 Kholkin A. I., Kuzmin V. I., Protasova N. V., *Zh. Neorg. Khim.*, 35, 7 (1986) 1886.