Leszek GOTFRYD[*]

SOLVENT EXTRACTION OF NICKEL(II) SULPHATE CONTAMINANTS

Potentials of the solvent extraction method for separation of contaminants, especially Co(II), from nickel(II) sulphate solutions have been reviewed. Properties of most important and commercially available organic preparations, making extractive separation of these elements possible, have been shortly characterized.

On the basis of laboratory investigations, behaviour of cationic liquid ion exchangers, Cyanex 272 and Cyanex 302, used for Co(II) and Ni(II) separation, has been compared. Co-extraction isotherms of most important contaminants, including Zn(II), Cu(II) and Co(II), with Cyanex 272, from solutions of nickel(II) sulphate have been examined. Next, the extractant has been applied to purification of the so called crude nickel(II) sulphate or CNS from the contaminants.

The CNS, a commercial product of technical grade, produced by Polish copper smelters, had been previously, before its further extractive purification treatment, prepared by leaching and dissolution in deionised water and by preliminary hydrometallurgical (oxy-hydrolytic) purification from iron(II), iron(III), arsenic(III), arsenic(V) and similar elements.

Pilot apparatus with continuous flow of all media, applied to the CNS purification, consisted of 5 extractors of the mixer-settler type, joined together to make adequate counter-current system 1-2-0-2. Washing of the organic phase had not been applied because of purposeful preparation of the system merely for common, not selective, collecting of all metal ions, contaminating CNS.

The system has reached an excellent purification level of nickel(II) sulphate. Obtained, as an additional product, the cobalt(II) sulphate concentrate (stripped solution) was almost totally neutralised (pH > 3.5).

Key words: solvent extraction, Co/Ni separation, Cyanex 272, Cyanex 302, nickel(II) sulphate, cobalt(II) sulphate, solution purification

INTRODUCTION

The Polish copper smelters currently produce an electro-refinery by-product, called the crude nickel(II) sulphate or CNS. The CNS is a technical grade commercial product sold for its nickel value. It would be economically much more justified to

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[*] Institute of Non-Ferrous Metals; Sowinskiego 5; 44-101 Gliwice; Poland, phone: (+ 048 32) 2 380 387; e-mail: leszekg@imn.gliwice.pl

separate pure NiSO$_4$ from contaminants, typically zinc(II), iron(II), copper(II) and cobalt(II) and make a further use of both nickel(II) and cobalt(II) sulphate concentrates obtained, to produce pure nickel(II) and pure cobalt(II) salts on the premises.

The goal of this work was to obtain Ni(II) and Co(II) concentrates from the CNS by solvent extraction technique. Features of this technique, when liquid cationic ion exchangers are used, create possibilities for sequential separation of the heavy metal simple ions in aqueous solution of their salts, for example sulphates, nitrates or diluted chlorides. They can be separated using the step by step approach or in bulk in arbitrarily limited extent (e.g. sole Zn(II) or Zn(II) with Cu(II) or Zn(II) with Cu(II) and Co(II)) from the rest of heavy metal ions present and from a bulk of common lighter cations such as sodium(I), potassium(I), magnesium(II), ammonium(I) and similar. Additionally, all anionic contaminants (chlorides/sulphates, fluorides, cyanides, arsenates and further) are fully rejected, being completely ignored by extractant of a cationic type.

This author, following recent achievements of the hydrometallurgy, has applied solvent extraction of metals, to investigate and solve the basic aim – transformation of the CNS technical product into pure NiSO$_4$ without loosing the chance to recover the remaining valuable metal salts.

SELECTIVE EXTRACTION OF COBALT(II) IN THE PRESENCE OF NICKEL(II)

First suggestion of extractive power of di(2-etylheksyl)phosphoric acid (DEHPA) for Co(II)/Ni(II) separation has been made by Ritcey and Ashbrook in 1966 (Ritcey 1969). A few years later, working for Eldorado Nuclear Ltd. and Canadian Department of Energy, Mines and Resources (further known as CANMET) they worked out a viable technology for Co(II)/Ni(II) separation using the mentioned extractive system. It was quite sophisticated, involving 8 stages of extraction and 4 stages of stripping at elevated temperatures. A few plants had been operated on this technological basis.

In the middle seventies of the XX century a second separation process, called Falconbridge, has been developed. It was based on extractive properties of aliphatic amines (trioctylamine), which extract anionic forms of cobalt(II) - e.g. CoCl$_4^{-2}$ from chloride aqueous solutions with a high selectivity. This idea was applied as a background of the SMMC Process (Sumitomo Metal Mining Co., Japan). Here, the nickel(II) and cobalt(II) chloride solutions, being the feed for selective extraction of Co(II), are obtained and preliminary purified from most of the contaminants by their common extraction from the sulphate solutions with the Versatic 911 (Shell Chemicals Co.) extractant. In those years Nippon Mining Co., within their NMC Process, exploiting initially the DEHPA (known in Japan as DP-8R, according to Daihachi Chemical Ind.), has changed it into Daichachi's PC-88A. This preparation (about 20-

fold more selective for Co/Ni separation) was based on alkyl-phosphinic acid. After short period, Shell Chemicals (SME 418 or earlier as RD 577) and Albright & Wilson (Ionoquest 801) have developed their own preparations for the same purpose and with similar formula. The main ingredient of all those was mono-2-etylhexyl(2-etylhexyl)phosphonic acid (Agatzini-L. 1997; Sole 1992; Tait 1993).

Nowadays, all mentioned reagents have been replaced with the Cyanex series (Am. Cyanamid Co. products): Cyanex 272, 302 and 301, distributed in Europe by Cytec Industries Ltd., France. The most important of them is Cyanex 272 – containing mainly bis(2,4,4-trimethylpentyl)phosphinic acid (76 %). Cyanex 302 and Cyanex 301 are its monothio- and dithio- derivatives. The last two, especially Cyanex 301, are not very stable in contact with Cu(II), Cd(II) and common oxidants. Table 1 illustrates great advantages of Cyanex 272 over earlier extractants (Preston 1983; Rickelton 1984). Additionally, Cyanex 272 almost does not extract calcium at the optimal for Co(II) extraction conditions (pH 5.0-5.5). This allow to avoid gypsum crystallisation in stripping-electrowinning circuits.

Table 1. Comparison of Co(II)/Ni(II) separation coefficients for various extractants

Extractant	β^{Co}_{Ni}	pH of optimal Co extraction	$\Delta pH_{50\%}^{Ni-Co}$	
			(20 ^{o}C)	(50 ^{o}C)
DEHPA	14	3.6-3.8	0.35	0.70
PC-88A	280	5,0	1.21	1.48
Cyanex 272	7000	5.3-5.5	1.58	1.94

β^{Co}_{Ni} = coefficient of Co(II)/Ni(II) separation = D(Co)/D(Ni); D(M) = coefficient of metal ion (M) distribution = concentration of M in organic phase divided by concentration of M in aqueous phase; $\Delta pH_{50\%}^{Ni-Co} = pH_{50\%}^{Ni} - pH_{50\%}^{Co}$; $pH_{50\%}^{M}$ – so called "pH of half extraction of ion M" ; that means for D(M) = 1.

Parameters β are not absolute and they depend on the pH value but they are useful for comparison of the abilities of extractants at fixed (individually optimal) conditions. Further physical and chemical data of the most important Co(II) extractants, are gathered and compared in Table 2 (Rickelton 1991; Rickelton 1992; Szymanowski 1997; Booklets)

Alkyl phosphonic and alkyl phoshinic acids as Co(II) extractants have one common and important disadvantage. If saturated to the level of 15-20 g/dm^3 Co(II) they highly increase their viscosity to over 150 cSt (even to 400 cSt). At such conditions mixing and pumping can be almost impossible. Maximal concentrations of extractants, and consequently of Co(II) extracted, should be limited to medium levels and/or elevated temperature should be applied to avoid problems of too high viscosity. The elevated temperature is moreover advantageous because the selectivity increases with rising of temperature.

Table 2. Physico-chemical parameters of bis(alkyl)phosphinic acids and DEHPA [20 ^{o}C]

Extractant	Main ingredient	Molar weight	pK$_a$	Density [g/cm^3]	Viscosity [cP]	Temp. [^{o}C] of...			Solub. in H$_2$O [mg/dm^3]
						melt.	boil.	ign.	
Cyanex 272	*R$_2$PO(OH)*	290	6.37	0.91	142	-32	>300	108	16
Cyanex 302	*R$_2$PS(OH)*	306	5.63	0.93	195	-20	205	96	3
Cyanex 301	*R$_2$PS(SH)*	322	2.61	0.95	78	-34	220*	74	7
DEHPA	*(R'O)$_2$PO(OH)*	322	3.95	0.97	56	-60	-	171	< 10

* - boiling with decomposition
R = 2,4,4-trimethylpentyl: $CH_3C(CH_2)_2CH_2CH(CH_3)CH_2$- ;R' = 2-ethylhexyl: $CH_3(CH_2)_3CH(C_2H_5)CH_2$-
, pK$_a$ = - log K$_a$ (K$_a$ – equilibrium constant of acidic dissociation).

There is a number of examples of extractant applications for Co(II)/Ni(II) separation in US patents issues (Patents) and in commercial brochures of Cytec Industry Ltd. (Booklets).

The solvent extraction technique for Co(II)/Ni(II) separation has been successfully applied in a few industrial plants, e.g. Matthey Rustenburg Refiners Ltd. (Transvaal, South Africa); Hitachi (Japan), Sudbury (International Nickel Co., Canada) /with the use of DEHPA at the beginning/; INCO, Outokumpu (Cyanex 272), SMMC Plant (Japan) (versatic acids and tertiary amines).

METHOD AND MATERIALS

The purpose of the work was to develop viable extractive system for purification of the CNS, to the maximal extent, from the Zn, Cu, Co and similar element mixtures. To achieve this, it was necessary to select best extractants and check extractive features of the elements (selective and collective), especially at the quasi-industrial conditions. That has meant quite wide spread preliminary screening investigations. The method involved identification of individual extraction and their dependencies on pH, their mutual comparative assessment and then more detailed studies on extraction isotherms for selected extractants at a constant pH of their optimal extraction as well as studies identifying isotherms of stripping. On this basis, the best extractant had been selected and counter-current extractive system has been designed. At the last stage, this extractive system has been evaluated on the pilot scale in a set of mixer-settlers type extractors. Each of them had 2.2/5.5 dm^3 of mixer/settler individual capacity.

PERCENT OF EXTRACTION VS. PH AND CLASSICAL EXTRACTION ISOTHERMS

Typical conditions of extraction were as follows:
- pure metal salt concentration – 0.02 to 0.10 M,
- neutralizing agent – 5.0 M NaOH pure solution,
- ambient temperature (about 20 ^{o}C),
- time of stirring - 10 minutes, also after each dose of NaOH solution added.

The percent of extraction measurements were performed by mixing a quite large volume sample of single metal sulphate solution with an equal sample of extractant (typically 0.350:0.350 dm^3/dm^3 at the beginning), then a sequential adding of small volumes of neutralizing agent (1.0 cm^3) and taking aliquot samples (25 cm^3) of both phases at every extraction equilibrium stage obtained.

To explore extraction and stripping isotherms, reacting phases were mixed together at a few various organics (O) to aqueous (A) volume ratios (typically from O:A = 10:1 to 1:10), to pick up a range of data: pairs of metal ion concentrations in both phases at consecutive extraction equilibria. If extraction itself was investigated, additionally, in all cases, small amounts of concentrated neutralizing agent were added to reach desired equilibrium pH level. For the stripping isotherm, the organic phase (extractant), was preliminary loaded with the metal ion at their individual optimal conditions, and then it was contacted with the solution of the chosen acid (H$_2$SO$_4$) with an arbitrary fixed initial concentration (typically 1.0 or 2.0 M).

CROSS-CURRENT EXPERIMENTS ON THE LABORATORY SCALE

The step by step investigation of extractive process should cover, as the next stage, laboratory experiments of chosen character (typically counter-current one). Details of such type of experiment could be found in literature (Gotfryd and Szymanowski 2004). Here, because of the simplicity of the extractive conditions, they were substituted by simpler cross-current ones, bearing information useful enough to design the pilot step of the counter-current experiment. They were performed under typical conditions of mixing time and temperature. Details are described in *Results* section.

COUNTER-CURRENT (C-C) EXPERIMENTS ON PILOT SCALE

A real C-C experiment of continuous character has been performed using a pilot plant equipment, consisting of a train of mixer-settler type extractors, arranged to exercise an optimal extractive system, developed in the previous laboratory steps of investigations. This was a configuration of the 1-2-0-2 type, consisting of one stage of extractant conditioning, two stages of extraction and two stages of stripping (without scrubbing). The reactors had the 2.2/5.5 dm^3 mixer/settler individual capacity. The value of pH was maintained automatically at the desired levels of 5.0-5.5 by controlled addition of 2.5 M NaOH solution.

MATERIALS

A series of extractants has been examined: DEHPA, Cyanex 272, Cyanex 302, Cyanex 301, LIX 54-100 (1-phenylnonandione-1,3), LIX 64N (2-hydroxy-5-nonylbenzophenone oxime), LIX 84-I (2-hydroxy-5-nonylacetophenone oxime) and also DIPSA (di(3,5-isopropyl)salicylic acid) / Cyanex 471X (tributylphosphine sulphide) combination. They were used as 0.2 M solution in kerosene-like dissolvents (Escaid 110 or Escaid 120 /Exxon/).

Preliminary experiments (pH dependencies and extraction/stripping isotherms) were performed using individual synthetic solutions of Zn(II), Cd(II), Cu(II), Co(II) and Ni(II) sulphates (pure). Main pilot trials of technological character were performed with a real CNS solution. It was prepared by leaching/dissolution of the technical CNS in hot deionised water and oxy-hydrolytic purification from iron, manganese, arsenic and further similar elements. The chemical compositions of the CNS and prepared nickel solutions are shown in Table 3.

Table 3. Crude nickel(II) sulphate (CNS) and its preliminary purified feed solutions (1, 2), directed to further extractive purification

	Element	Ni	Co	Cu	Zn	Pb	Ca	Mg	Fe	As	H_2O
CNS	%	29,4	0,52	0,58	0,15	0,012	1,19	0,080	0,60	0,075	3,02
1	g/dm³	74.3	1.14	0.90	0.27	0.0033	0.64	0.20	< 0.001	0.0007	-
2		72.0	1.3	1.48	0.34	0.011	0.50	0.21	0.36	<0.005	-

RESULTS AND ANALYSES

EXTRACTION VERSUS pH

Typical results of extraction versus pH measurements are presented on Figure 1, showing selected metal extraction curves obtained for Cyanex 272.

The horizontal line at the level of 50 % extraction cuts the isotherm curves and indicates the individual values of $pH_{50\%}$ for each metal cation extracted, a parameter characterising the extractant-metal mutual behaviour. All of the values obtained during investigation with a few selected cations extracted from sulphate solutions with various 0.2 M extractants, are gathered in Table 4.

Treating the value of $\Delta pH_{50\%} = pH_{50\%}(Ni) - pH_{50\%}(Co)$ as an indicator of impurities vs. Ni(II) separation ability, it was easy to state, that the optimal extractant, with characteristics suitable for the Ni(II) purification from Co(II) ($\Delta pH_{50\%} = 1.7$), Zn(II) and Cu(II), is Cyanex 272. The next ones, but less effective, can be Cyanex 302 (0.8), Cyanex 301 (0.7) and DEHPA (0.6). All three LIX and DIPSA/Cyanex 272 combinations were eliminated as potential extractants of Ni(II) contaminants, as having too high $pH_{50\%}$ level of the Zn(II) extraction.
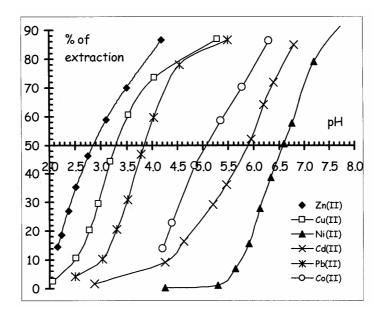
Fig. 1. Extraction of metal cations with 0.2 M Cyanex 272. Dissolvent - Escaid 110 (Exxon); temp. 20
^{o}C; mixing time – 10 min.; metal salts conc. as indicated in table 4 and Pb^{2+} as 0.05 M lead(II) nitrate

Table 4. Equilibrium pH of 50 % extraction of metal cations

Extractants	Salt conc. [mol/dm^3]	pH$_{50\%}$					ΔpH$_{50\%}$
(concentration - 0.2 M)	(sulphates)	Zn	Cd	Cu	Co	Ni	Ni-Co
Cyanex 272	0.10	2.75	5.9	3.3	5.0	6.7	1.7
Cyanex 302	0.02	1.4	0.5	-	3.4	4.2	0.8
Cyanex 301	0.10	-0.5	1.3	<1.0	0.7	1.4	0.7
DEHPA	0.10	1.8	3.1	3.1	3.6	4.2	0.6
DIPSA/Cyanex 471X*	0.05	5.1	4.3	3.8	-	-	-
LIX 54-100	0.05	6.32	-	-	-	-	-
LIX 64N	0.05	5.92	-	-	-	-	-
LIX 84-I	0.05	6.13	-	-	-	-	-

* - dissolved in Solvesso 150 (Exxon)

ISOTHERMS OF EXTRACTION OF CO(II) AND OTHER CNS CONTAMINANTS

Cyanex 272 and Cyanex 302 were proven as the Co(II) extractants by comparing their extraction (from 0.1 M CoSO$_4$ pure solutions) and stripping (with 2 M H$_2$SO$_4$ pure solution) isotherms. They showed, by comparison of the McCabe-Thiele

constructions, plotted for the counter-current extractive systems, that Cyanex 272 is the more effective extractant, especially from the stripping conditions point of view. A number of counter-current stages necessary to obtain almost total solution purification and complete Co(II) stripping had been found. They are as follows: 2/3 for Cyanex 302 and 2/2 for Cyanex 272 (extraction/stripping). The last system has been fixed as a basic one for the execution of the next steps of investigations, covering real continuous experiments, performed on a small pilot plant installation.

ISOTHERMS OF COMMON EXTRACTION VS. pH

The first step of investigation on the natural solution of a semi-industrial origin were measurements of common extraction isotherms of all important impurities. The results in Table 5 illustrate characteristic behaviour of the contaminants of the crude nickel sulphate. All of them are step-by-step eliminated from the $NiSO_4$ solution with rising pH, and there is seen their characteristic sequence: Zn(II) > Fe(II) > Cu(II) > Co(II).

A perfect repetition of this experiment with solution 2, having a decreased level of the initial Fe(II) concentration to 0.08 g/dm^3, has led to almost the same result without any physical difficulties. Separation of reacting phases was also good.

Table 5. Extraction of CNS contaminants versus equilibrium pH

	pH	Concentrations in aqueous solution [g/dm^3]			
	-	Co(II)	Cu(II)	Fe(II)	Zn(II)
1	2.13	1.21	1.44	0.24	0.28
2	2.92	1.21	1.41	0.033	0.044
3	3.91	1.18	1.16	0.065	0.0018
4	4.95	0.49	0.10	0.02	< 0.0002
5	6.05	0.033	0.007	< 0.001	< 0.0001

Stationary experiments on solution 2 (table 3; Ni = 72 g/dm^3); 0.2 M Cyanex 272/Escaid 110; O:A volumetric ratio = 1:1; time of mixing - 10 min.; temperature - 20 ^{o}C; 25 % NH_3 as neutralising agent; "lazy" phases disengagement

CLASSICAL ISOTHERMS OF COMMON EXTRACTION OF ALL IMPORTANT CONTAMINANTS OF CNS

The investigations were performed on the purified CNS solution 2 (Table 3) by the method described in the *Procedures* section. The results are shown on Figure 2.

The presence of Zn(II) and Fe(II) depresses extraction of Cu(II) and Co(II) but all of them can be extracted commonly when proper values of pH and organic-to-aqueous ratio is maintained, covering a necessary capacity to contain all of them. As previously, the presence of Fe(II) was the reason of some problems with phase separations, therefore it should be removed before extraction.
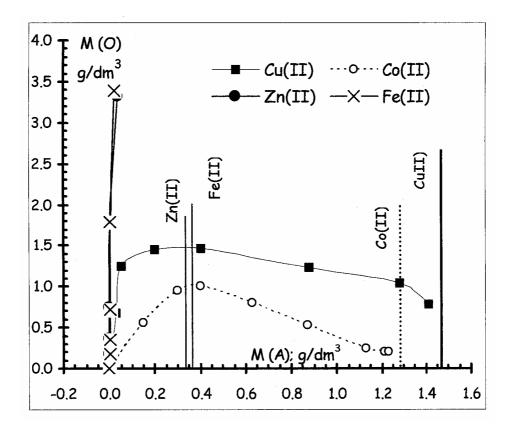
Fig. 2. Isotherms of common extraction of CNS contaminants. Vertical lines indicate initial levels of contaminants (solution 2 - table 3); temp. 20 °C; mixing time - 10 min.

CROSS-CURRENT LABORATORY EXPERIMENTS

Instead of rather laborious counter-current extractive experiments (described in details by Gotfryd and Szymanowski, 2004), simple laboratory tests of the cross-current character confirmed possibilities of easy common extraction of all the CNS contaminants. The extractant was preliminary prepared by contact with the Na_2SO_4 solution and adjusting pH with 5.0 M NaOH solution to the level of 7.0 and then contacted one, two or three times with the solution 1 (Table 3). The results and other conditions are shown in Table 6.

COUNTER-CURRENT EXPERIMENTS

A laboratory step of counter-current extraction of CNS contaminants was skipped, basing on the results shown in Table 6. An experiment using the pilot counter-current equipment, consisting of five mixer-settler type extractors, was performed.

Table 6. Cross-current extraction of CNS contaminants

Step	I	II	III	I	II	III	Last step
	O : A			equilibrium pH			Co (A)
No.	phase ratios [dm^3/dm^3]						[g/ dm^3]
1	1 : 2	-	-	4.8-5.0	-	-	0.1-0.2
2	1 : 2	1 : 2	-	4.8-5.0	5.2-5.4	-	0.017-0.020
3	1 : 2	1 : 1	-	4.8	5.45	-	0.008
4	1 : 2	1 : 2	1 : 2	4.9	5.0	5.1	< 0.001
5	1 : 1	1 : 1	-	4.8	5.4	-	< 0.001

Extractant: 0.2 M Cyanex 272 / Escaid 110; feed: solution 1 (table 3); temperature - 20 $^{\circ}$C; time of mixing – 10 min.; pH regulated with 2.5 M NaOH.
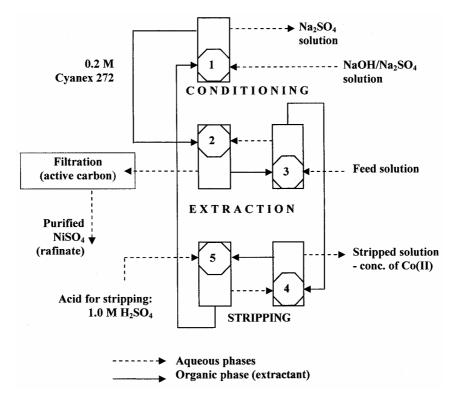

Fig. 3. Continuous counter-current extractive system designed for CNS purification. Extractant: 0.2 M Cyanex 272 / Escaid 110; feed: solution 1 (table 3)

They were arranged into the 1-2-0-2 counter-current system. The figures designate numbers of necessary extractive stages for all extractive processes, contributing to the whole procedure, consisting of conditioning – extraction itself - washing – stripping. A scheme of the designed extractive system is shown Figure 3. As the feed Solution 1 (Table 3) was used.

After reaching and stabilizing the optimal conditions, the level of Co(II) in the purified $NiSO_4$ solution was as low as < 0.01 g/dm^3 and concentrate of metals was totally neutralized. The compositions of the both resulting solutions are shown in Table 7.

Table 7. Composition of the samples of stripped solution (Co concentrate) and Ni rafinate, taken at optimal conditions of pilot plant extractive experiment

	Co(II)	Cu(II)	Ni(II)	Zn(II)	Mg(II)	Ca(II)		pH
Co concentrate	27.2	18.3	6.0	5.5	1.8	0.7	g/dm^3	3.5
Ni rafinate	0.005	< 0.001	72	< 0.001	-	0.2		5.2

DISCUSSION AND CONCLUSIONS

The obtained results confirmed an expectation, that Cyanex 272 is the most adequate extractant for the purpose for which the investigations had been carried out – that's to find an extractive purification method for crude nickel(II) sulphate, enabling its most common contaminants (Zn(II), Cu(II) and Co(II)) removal. 0.2 M Cyanex 272 in Escaid 110 (Exxon) has been used for all further investigations.

The presence of Fe(II) is the reason of important physical disturbances at the phase border of the reacting media and additionally, taking into account that Fe(III) is known as being extracted very strongly, both cationic forms of iron should be removed from solutions directed to the extractive purification. The oxy-hydrolysis seems to be a good enough method for their removal (along with manganese and arsenic) before applying the solution to further purification by extraction. Ammonia could be used as a neutralizing agent in diluted Ni(II) solutions. To avoid the precipitation of mixed Ni(II)/NH$_4$(I) sulphates, the concentrated (2.5-5 molar) solution of NaOH should be chosen for more concentrated solutions of $NiSO_4$.

The shapes of extraction isotherms, analysed by the McCabe-Thiele pattern, and results of simplified laboratory cross-counter experiments has led to designing an extractive system, consisting of one-step extractant conditioning, two steps of extraction (without washing) and two steps of stripping (1-2-0-2 type of counter-current system). This has been successfully examined on pilot scale apparatus, giving purified $NiSO_4$ solution and Co(II) concentrate suitable for further extractive purification.

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Gotfryd L., *Rozpuszczalnikowa zanieczyszczeń siarczanu niklu(II),* Physicochemical Problems of Mineral Processing, 39 (2005) 117-128 (w jęz. ang)*.*

Dokonano przeglądu literaturowego potencjalnych metod ekstrakcyjnego oddzielania zanieczyszczeń, w szczególności Co(II), z roztworów siarczanu niklu(II). Krótko scharakteryzowano właściwości ważniejszych dostępnych na rynku preparatów organicznych, umożliwiających ekstrakcyjne oddzielanie tychże zanieczyszczeń. Na podstawie badań laboratoryjnych porównano zachowanie się ciekłych wymieniaczy jonowych, Cyanexu 272 oraz Cyanexu 302, wobec Co(II) i Ni(II). Wykorzystując Cyanex 272 zbadano izotermy współekstrakcji najważniejszych zanieczyszczeń, w tym Zn(II), Cu(II) i Co(II), z bogatych roztworów siarczanu niklu(II). Następnie, ekstrahent ten został zastosowany do głębokiego oczyszczenia surowego siarczanu niklu(II) (SSN), od tych zanieczyszczeń. SSN jest technicznej jakości produktem handlowym, produkowanym przez polskie huty. Przed obróbką ekstrakcyjną, został wstępnie przygotowany poprzez roztworzenie w gorącej wodzie zdemineralizowanej i hydrometalurgiczne (oksyhydrolityczne) oczyszczenie od żelaza(II), żelaza(III), arsenu(III), arsenu(V), itp.

Aparatura pilotowa, o ciągłym przepływie mediów roboczych, zastosowana do oczyszczania SSN, składała się z 5 ekstraktorów typu mieszalnik-odstojnik, połączonych w odpowiedni układ przeciwprądowy typu 1-2-0-2. Nie zastosowano przemywania fazy organicznej ekstrahenta ze względu na świadome przygotowanie systemu wyłącznie do wspólnego, nie selektywnego, oddzielenia wszystkich jonów, zanieczyszczających SSN. Uzyskano znakomity poziom oczyszczenia siarczanu niklu(II). Pozyskany ponadto dodatkowy produkt, koncentrat siarczanu kobaltu(II) (roztwór poreekstrakcyjny) był niemal całkowicie neutralny (pH > 3,5).