



TREATMENT AND RECOVERY OF NICKEL RICH PRECIPITATE FROM PLATING PLANT WASTE

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Abstract. Nowadays, with the environmental regulations becoming more and more stringent and growing pressure on the conservation of mineral resources, recycling has been gaining interest to develop economically-viable refining technology. As the costs of the wastewater disposal increase (especially in the metal finishing industry) more emphasis is being placed on the recovery and recycling of valuable chemicals contained within these streams.

In this study, a commercial plating plant filter waste (PPFW) was examined as an alternative source for the recovery of Ni as a nickel rich precipitate. The treatment tests performed by H_2SO_4 leaching method showed that dissolution amounts of metals such as Ni, Cu, Zn and Cr were affected by leaching time, temperature and acid concentration. Although the dissolution of metallic compounds almost was completed within the one hour of the extraction time, a rapid and higher dissolution amounts of Ni within the first minute of the leaching process (approximately 81% of the total extractable amount of Ni is extracted at the beginning period for 24 °C) indicated that the usage of this waste as a source of Ni has an advantage compared to Ni recovery from natural ores. A kinetic study carried out to clarify the dissolution of Ni, showed that a series of rate controlling steps, both chemical and diffusion reactions, was involved in the observed kinetic. After leaching, the filtered solution was subjected to two stages of controlled precipitation carried out at a pH of about 4–5.5 and about 8 to produce the solids containing non-nickel and nickel respectively. The precipitation test performed by NaOH or MgO showed that almost all of the dissolved Ni ions were separated from the solution. Based on the XRD and IR analysis, it was found out that a final precipitate, obtained by the use of NaOH, could be characterized as a disordered α -Ni(OH) or as a blend of α and β -Ni(OH)₂, as for the MgO, the precipitate composed of mainly β -Ni(OH)₂ phase and/or α -Ni(OH)₂ phases.

Keywords: plating plant waste, treatment, Ni recovery, leaching, precipitation, recycling.

1. Introduction

The treatment of processed effluents is the most serious environmental issue faced by the processing industries. Wastewater streams may contain heavy metals, organic waste, and oils, including the waste liquids generated by metal finishing or the mineral processing industries. Toxic metals, probably existing in high concentrations, must be effectively treated / removed from the wastewaters (Barnes *et al.* 1981). However, the disposal process can bring about some difficulties. Besides the environmental sensitivity, the companies are also suffering from an increased disposal cost. This has led to focus on their ability to clean up this waste and return or recycle a significant proportion. The corrosion resistance of ferrous metal products is commonly rendered by the application of electroplated coatings of non-ferrous metals such as zinc, nickel, copper, cadmium and chromium. Liquid effluents from plating plants, mainly consisting of the mixture of washing water and hazardous plating chemicals, must be treated prior to the release of the wastewater into the environment. The treatment of these effluents is typically performed by the adjustment of the pH of the wastewater from 8 to 11 to precipitate the metallic cations as the corresponding hydroxide, which is then filtered to yield toxic heavy metal sludge. The pre-treated sludge is

not reusable in plating baths since it contains a substantial amount of harmful chemicals, iron and water hardness factors (Frankard 1987; Rivoallan *et al.* 1994). Therefore, it must be shipped to environmentally-secure landfill sites or incineration plants. The cost of such safe permanent disposal is very high, and can equal or exceed the value of the chemicals used in the plating process. In some countries the incapability of the incineration plants to treat the hazardous waste also leads to unlawful disposal of this waste into the soil. Therefore, there are very stringent national waste framework directives based on the “Basel Convention” forcing producers to employ the treatment or recovery methods in situ and recycle the valuable metals or chemicals in process. Furthermore, this waste, which is generally regarded as a hazardous, could be considered as a rich source of a secondary metal such as nickel and chromium.

In this study, a commercial PPFW was treated by hydrometallurgical method in order to find out the recovery of valuable metals as a metal reaches precipitate, i.e. nickel rich precipitate and the safe disposal of filtered solid product after the leaching process. The H_2SO_4 leaching was employed to extract the valuable metals from waste sludge. The effects of the test parameters such as reagent concentration, time and temperature on extraction process were investigated. A special emphasis was

also given to the kinetics of nickel dissolution. After leaching, the solution was subjected to two-stage controlled precipitation leading to selective separation of dissolved metallic species as hydroxide forms. XRD, XRF, IR and SEM techniques were also employed to characterize the resulting precipitates.

Background of the recovery method

The ability to recover metals economically after end-of-life is largely a function of their chemical reactivity and how they are initially used in economy. In a general route, a scrap metal in a solid form is subjected to the pyrometallurgical recycling route while those arising in liquid form, such as spent electrolytes from electrochemical processing of metals, are recycled by hydrometallurgical methods (Moore 1993). A typical processing of nickel from Ni-ore consists of the extraction of Ni, Co and other metals such as Mn, Mg and Fe from the ore into the aqueous phase and treatment of leach solution to produce a precipitate containing Ni and Co and further treatment of the precipitate to separately recover Ni and Co at a satisfactory level of purity. The last stage may involve further leaching to extract Ni and Co, followed by SX (Solvent extraction) to separate the Ni selectively (White 2002). Operating experiences and a number of research studies performed to separate nickel from other dissolved metallic species showed that the precipitation of nickel as nickel hydroxide ($\text{Ni}(\text{OH})_2$) by using alkaline reagent has some processing difficulties such as selectivity, settling time, purity etc (Oustadakis *et al.* 2006). For this reason the precipitation condition should be optimized to reduce the impurity uptake and improve the settling characteristics. For example, Sist and Demopoulos (2003) reported that the use of the stepwise neutralization (controlled precipitation) at relatively higher precipitation temperature ($>50\text{ }^\circ\text{C}$) aids to the generating of well-grown crystalline particles. Recently Jones (2001) also discloses a precipitation process for selective separation of nickel and cobalt ions from other dissolved ions such as copper, zinc, iron, magnesium and manganese, when the leach solution does not contain sufficient amount of zinc and copper for solvent extraction.

In practice, slaked lime ($\text{Ca}(\text{OH})_2$) is preferred as a precipitation reagent due to its relatively low cost. How-

ever, it should be considered that precipitation by using $\text{Ca}(\text{OH})_2$ can result in formation of insoluble calcium sulfate- precipitate which causes contamination of the nickel product. The use of MgO as an alternative precipitation reagent has also been suggested by several researchers (Kay 2002; Oustadakis *et al.* 2006). Based on such studies, it can be concluded that relatively purer and more sufficient amount of precipitated $\text{Ni}(\text{OH})_2$ is obtained under a stringent pH control and relatively higher precipitation temperature ($\sim 55\text{ }^\circ\text{C}$).

2. Experiment

2.1. Materials

The PPFW used in laboratory experiments was supplied by a commercial electro-plating plant, Eskisehir-Turkey. This plant disposes nearly 70 tons waste of sludge annually. The chemical composition (determined by the XRF, X-Ray Fluorescence, Philips PW-2404) of a representative waste material is given in Table 1.

Table 1. Chemical analysis results of PPFW

Oxide	Weight %
MgO	4.57
Al_2O_3	8.85
SiO_2	2.91
P_2O_5	2.13
SO_3	15.2
CaO	23.0
Cr_2O_3	8.88
NiO	9.46
CuO	1.71
ZnO	1.44
LOI*	20.1

*Loss of ignition

The crystalline mineral phases of PPFW were determined by using X-Ray-Diffraction (XRD), model S5000 diffractometer. In regard to the XRD analysis, it was discovered that PPFW mainly consisted of hannebachite, $\text{CaSO}_3 \cdot \text{H}_2\text{O}$ (HA), calcium silicate (CS), portlandite (P), little amount of nickel chromium oxide (NCO), calcium chromium oxide (CCO) and aluminium chromium silicate (ACS) and quartz (Q) (Fig. 1).

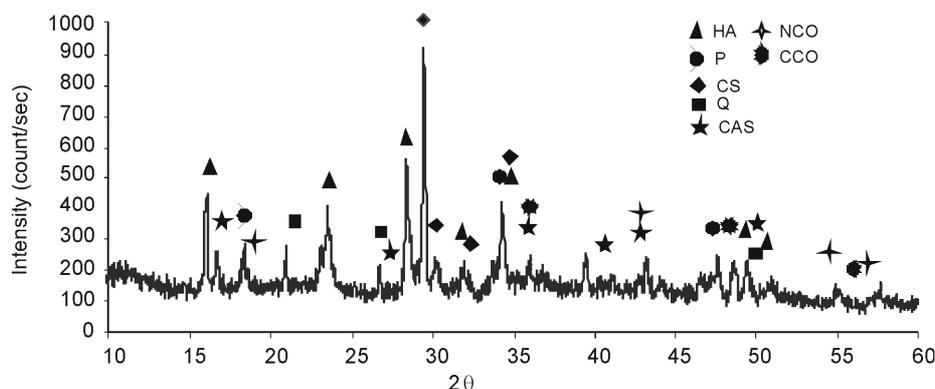


Fig. 1. XRD diffractogram of raw PPFW

2.2. Methods

The bench type leaching experiments were performed to provide the necessary information about the re-usability of the metallic compounds in PPFW instead of their disposal. The dissolution tests were carried out in a 1L three-necked round-bottom flask reactor placed on a temperature controlled magnetic stirrer. In each test a 10 g of sample was added into 0.5L H₂SO₄ solution and then stirred at a fixed stirring speed of 450 rpm. 10 mL of solution were taken at predetermined time intervals to evaluate the effect of reaction time, acid concentration and leaching temperature on metal dissolution. After leaching, the solution was filtered and subjected to two-stage controlled precipitation process in order to selectively separate the dissolved metals from the leached solution. The precipitation tests were performed by drop-wise addition of 1 Mol L⁻¹ NaOH or MgO (10% by weight) into 100 mL of the leached solution (1N H₂SO₄ at 24 °C). For the first stage of precipitation, the pH of the solution was slowly raised to about 4–5.5 to produce a solid containing non nickel and then filtered solution was subjected again to the second stage precipitation at a pH of about 8 to separate the dissolved Ni from the leached solution. The temperature was kept at 55 °C during the precipitation tests. The resulting precipitates were filtered, washed with distilled water and dried in an oven at 100 °C. All precipitates were characterized by a partial size analyzer Malvern, Mastersizer 2000, powder X-ray diffractometry, IR spectroscopy (Shimadzu HMV 2000-L FTIR spectrometer, cm⁻¹ resolution, KBr pellets) and scanning electron microscopy (Zeiss Evo 50 VP). The chemical analysis of dissolved species was performed by Atomic Absorption Spectrometer (AAS).

3. Results and discussion

3.1. Effect of leaching time and H₂SO₄ concentration

The effect of leaching time on the dissolution amount of nickel and other main metals in PPFW, leached with 1N H₂SO₄ at 24 °C, is shown in Fig. 2. As seen from Fig. 2, the amount of dissolved metals increased extending the leaching time. However, the extraction process remained constant after 1h. The extraction percentage of Ni, Cr, Zn and Cu was calculated as 84%, 35%, 79% and 86% respectively. A lower extraction percentage of Cr compared to other metallic compounds in PPFW can be attributed to the high resistance or insolubility of the chromium-aluminum silicate in diluted H₂SO₄ solution.

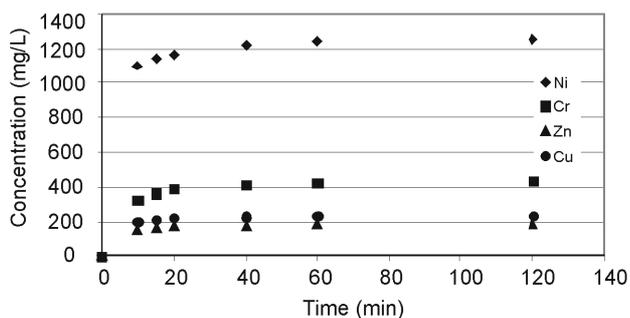


Fig. 2. The dissolution of nickel and other main metals as a function of leaching time

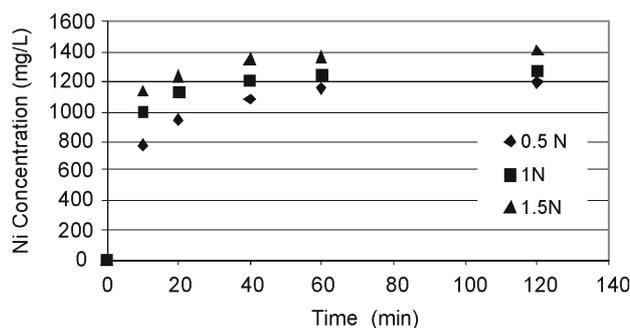


Fig. 3. Effect of H₂SO₄ concentrations on Ni extraction

Fig. 3 also indicates that the increase in H₂SO₄ concentration had a positive effect on the dissolution process. The total extraction percentage of Ni was increased from 84% for 0.5 N to 87% for 1 N; and 95.5% for 1.5 N acid concentration respectively.

3.2. Effect of temperature on nickel dissolution and leaching kinetics

The temperature (ranging from 24 to 55 °C) test results, obtained by the leaching of PPFW at constant solution concentration of 1N H₂SO₄ are presented in Fig. 4. It was found out that a rapid dissolution of Ni occurred at the beginning period (within one minute) of the leaching process for all temperature values. Although the dissolution processes beyond this stage, continued up to a certain value for each temperature, the dissolution rate of Ni decreased with the time progression. This suggests that there's a series of steps in which more than one rate controlling process is involved in the observed kinetics. The rapid reaction of Ni at the beginning of leaching (1st stage) is probably due to the dissolution of surface metallic hydroxides. This change appears to be a separate process (chemical reaction). On the other hand, the dissolution rate of Ni beyond the plateau value (Δn_p), the end point of first stage, is considerably lower than that of the first stage for all temperature. The extracted amounts of Ni within the 60 minutes of leaching time were calculated approximately 84%, 92% and 99% for 24, 45 and 55 °C, respectively. Approximately 81% of the total extractable amount of Ni was extracted at the initial period for 24 °C.

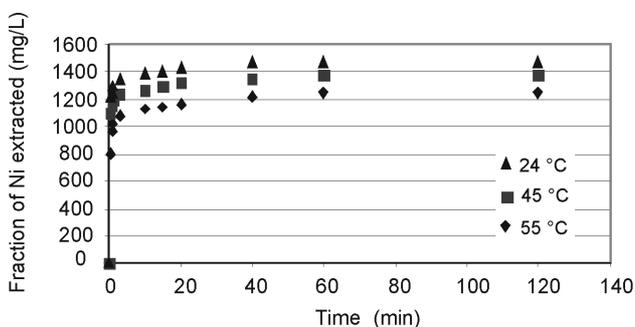


Fig. 4. Effect of temperature on the dissolution process

By increasing the temperature from 24 °C to 55 °C, the dissolution percentage of Ni increased from 84% to 99% in which 87% of Ni was extracted in the 1st stage. A rapid and higher dissolution percentage of Ni within the

first minute even at room temperature suggests that the usage of this waste as a source of Ni has an advantage compared to Ni recovery from natural ores. The XRD diffractogram of the leach residue obtained from the leached of PPFW at 55 °C shows that Gypsum (CaSO₄) is a main environmentally inert solid product that formed after the metals leaching process (Fig. 5). Hence the slower reaction rate observed in 2nd stage could be attributed to the formation of the product layer on the reacting surface and diffusion of reactant (H₂SO₄) through this product.

A normalized extraction curve, obtained by using a well known equation of $1 - \frac{2}{3} \alpha - (1 - \alpha)^{2/3} = kt$ (Sohn and Wadsworth 1979), and the slope of each line K_p values (parabolic rate constant) are given in Fig. 6 and Table 2 respectively (α = fractional amount of element leached, k = rate constant, t = time). The reacted amounts for each temperature were calculated by interpolating the concentration / time data after one minute of the zero time and zero concentration. The experimental activation energy for the diffusion process was calculated as 12 Kcal /mol.

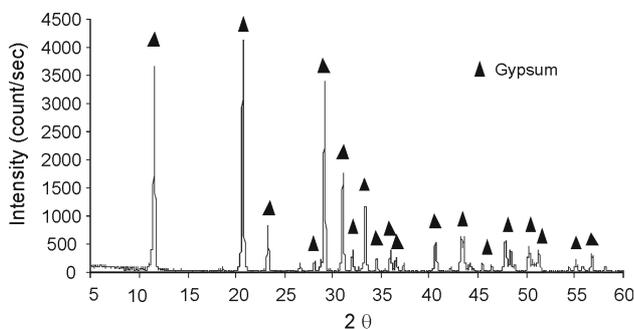


Fig. 5. The XRD diffractogram of the leach residue, obtained from the extraction of PPFW at 55 °C

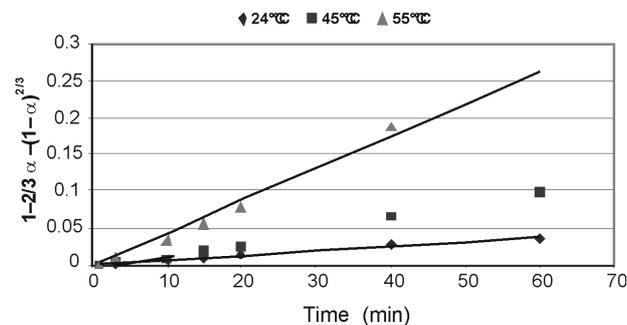


Fig. 6. A plot of $1 - \frac{2}{3} \alpha - (1 - \alpha)^{2/3}$ for PPFW as a function of time

Table 2. Calculated K_p rate constant

Temperature, °C	$K_p \text{ min}^{-1}$
24	6.10^{-4}
45	$1.6.10^{-3}$
55	$5.1.10^{-3}$

3.3. Precipitation

The precipitation tests showed that the solution pH and metal concentration strongly affect the precipitation of the dissolved ions, especially in the first stage of precipita-

tion (Fig. 7). The dissolved amounts of metal ions such as Cu, Zn and Cr decreased from 4.50 to 5.50 for both types of reagents with the pH increase. A relatively lower amount of dissolved ion concentrations in leach solution after the 1st precipitation by using MgO reagent, may thought to be a slow release of hydroxyl ion by MgO compared to NaOH that resulted in lower metal ion concentration in solution due to the beneficial effect on the growing of hydroxide particles, as previously reported by Sist and Demopoulos (2003) for Ni precipitation. The particle size analyses of precipitates by using NaOH (P-Na) and MgO (P-Mg) showed that a type of the considered reagent did not have a significant effect on the particle size of the final precipitate. The d_{50} and d_{90} values of the P-Na were 22.58 and 53.16 μm , whereas by using MgO pulp instead of NaOH, the d_{50} and d_{90} values of the precipitate were determined as 21.51 and 60.93 μm respectively. This can be attributed to a higher precipitation temperature (55 °C) than that of normally applied (24 °C). The precipitation and the crystallinity increased with the rise of temperature. The un-detectable Ni(OH)₂ peaks (XRD analyses) of the final precipitates, which performed at room temperature, confirmed this finding. The chemical analysis' results of the final solution showed that the separation of dissolved metallic species from leach solution was achieved effectively at the end of the precipitation stages. Nevertheless, the selective separation of nickel was not obtained at the 2nd stage of precipitation. The final precipitates still contained a little amount of zinc. This can be attributed to the closeness of the precipitation pH of the dissolved metals such as Zn and Ni with the existing ion concentrations in solution after leaching.

According to the chemical compositions of the final precipitate, P-Na and P-Mg, the purer precipitate can be

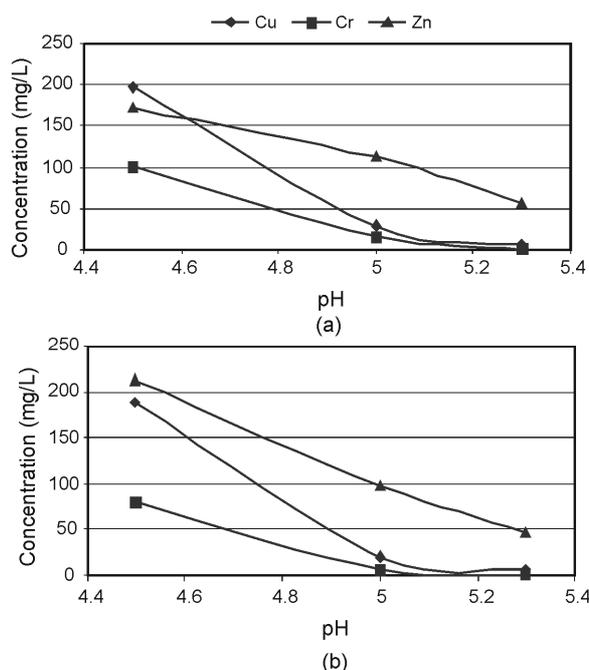


Fig. 7. Effect of solution pH on the metal ion concentrations as a function of precipitation reagents; NaOH (a) and MgO pulp (b)

obtained by using NaOH (Table 3) but these precipitates can only be evaluated as pre-concentrates for further selective separation processes such as ion exchange or solvent extraction.

Table 3. Chemical analysis of final precipitates for main metallic oxide

Oxide	P-Na (wt. %)	P-Mg (wt. %)
MgO	2.91	53.63
Al ₂ O ₃	0.07	0.06
SiO ₂	4.82	2.84
CaO	2.58	0.92
Cr ₂ O ₃	0.07	0.10
NiO	58.74	33.70
CuO	1.43	0.55
ZnO	7.01	3.28

3.4. Characterization of the precipitate

In order to characterize precipitates a series of structural and microstructural analyses were also performed. Regarding the X-ray diffraction data of the precipitates, obtained at the 2nd stage (Fig. 8a, b), it was discovered that the P-Na and P-Mg mainly consisted of Ni(OH)₂ having different polymorphism and Brucite (Mg(OH)₂) phases. It was established as well that nickel hydroxide mainly exists in two polymorphic forms, α and β . The β -(Ni(OH)₂) is isostructural with brucite and consists of an ordered stacking of well oriented Ni(OH)₂ slabs (β form). This anhydrous phase exhibits hexagonal platelet morphology, and OH groups of the adjacent layers are not hydrogen bonded. However, α -Nickel hydroxide phase is not only simple hydrated hydroxides but also hydroxyl deficient, including a variety of anions in the interlayer region along with water molecules (Kamath and Subbanna 1992).

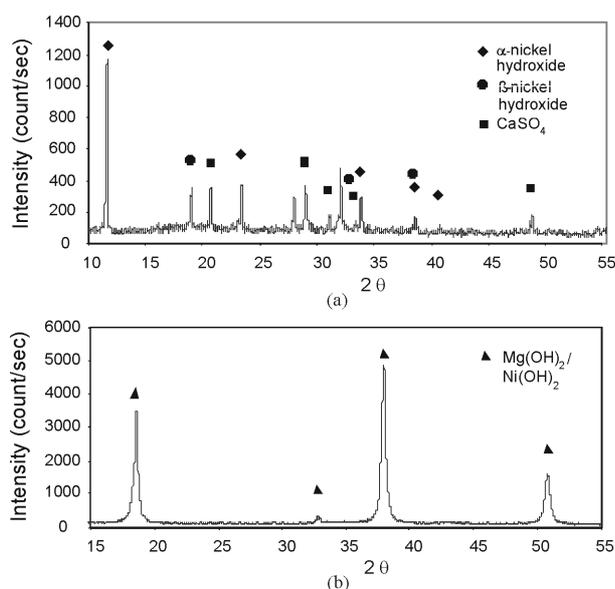


Fig. 8. X-ray diffraction data of the precipitates at a precipitation pH of about 8; P-Na (a) and P-Mg (b)

Except the well known polymorphisms, different forms of nickel hydroxide phases such as β_{bc} , (badly crystallized), a short-range structure of nickel hydroxide phases having

both α and β phases, α -LDH (layered double hydroxide) and a novel nickel hydroxide phases (neither α nor β) were reported in literature (Jayashree and Kamath 2001; Kamath *et al.* 1997; Rajamathi *et al.* 1997). In Fig. 8a, detected peaks at 7.62, 3.84, 2.64 and 2.33 Å indicate the existing of α -form Ni(OH)₂, while, other peaks, which appeared at 4.65, 2.69 and 2.33 Å, may also assign the minor amount of β -(Ni(OH)₂) phases in P-Na.

Thus, it can be concluded that the use of NaOH as a precipitation reagent has mainly resulted in the occurrence of a disordered α -form Ni(OH)₂ or a nickel hydroxide having features of both α and β phases. On the other hand, the XRD pattern of the P-Mg (Fig. 8b) shows that P-Mg consists of mainly Mg(OH)₂ and/or β -(Ni(OH)₂) phases and α -(Ni(OH)₂) phases.

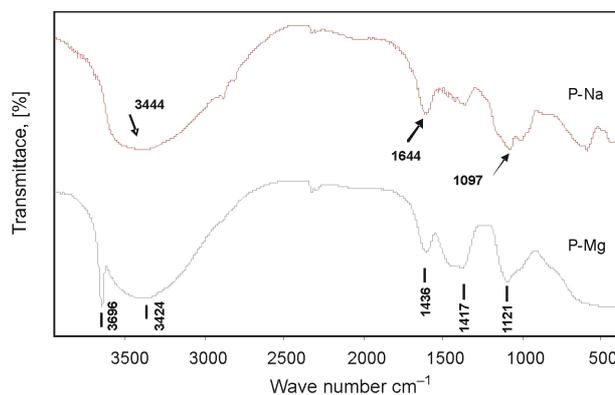


Fig. 9. IR spectrum of the precipitates; P-Na and P-Mg

The IR spectrum of both P-Na and P-Mg is given in Fig. 9. According to Fig. 9, P-Na could be characterized as a disordered α -Ni(OH) or as a blend of α and β -Ni(OH)₂. The well detected broad band centred around 3400 cm⁻¹, characteristic of α -Ni(OH)₂, is due to the ν (OH) mode of the hydroxide groups. This is involved in hydrogen bonding both from Ni(OH)₂ sheets and the adsorbed H₂O, indicating the existence of α -Ni(OH)₂ as described by earlier research report (Deabate *et al.* 1999). In addition to this characteristic band, three visible bands were also detected; the first band, which is around 1630 cm⁻¹ was due to the interaction of water molecules with Ni(OH)₂ by hydrogen bonding. The second band centred around 1100 cm⁻¹, due to the mixture of single- and double-bonded SO₄²⁻ ions absorption, and finally, the third absorption band around 640 cm⁻¹ show strong absorption which is normally expected for α -phase. The presence of the characteristic sharp peak at 3650–3694 cm⁻¹, due to non-hydrogen bonded OH groups stretching vibration, can refer to the P-Mg consisting of mainly Mg(OH)₂ together with β -Ni(OH)₂. Although the observed ν (OH) band centred at 3400 cm⁻¹ may be attributed to the existence of α -Ni(OH)₂.

The scans of electron micrographs of samples P-Na and P-Mg are shown in Fig. 10 and 11, respectively. The P-Na sample mainly consists of irregularly shaped chunky particles, generally observed for α -Ni(OH)₂, and also a little amount of relatively small granular particles. Though a different particle morphology was observed for P-Mg. This can be seen from Fig. 11b, where the precipitate

consists of many tiny agglomerated spherical particles. These particles sometimes occurred as smaller granular particles sticking to their faces, as reported earlier by Jayashree and Kamath (2001). These micrographs indicate the effect of precipitation reagent on the structure morphology of the resultant precipitate and confirm the above finding determined by XRD and FTIR characterizations.

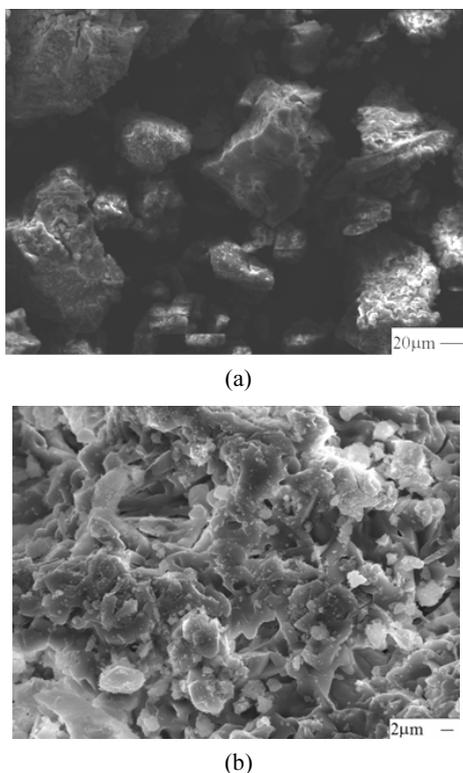


Fig. 10. Scanning of electron micrograph of P-Na

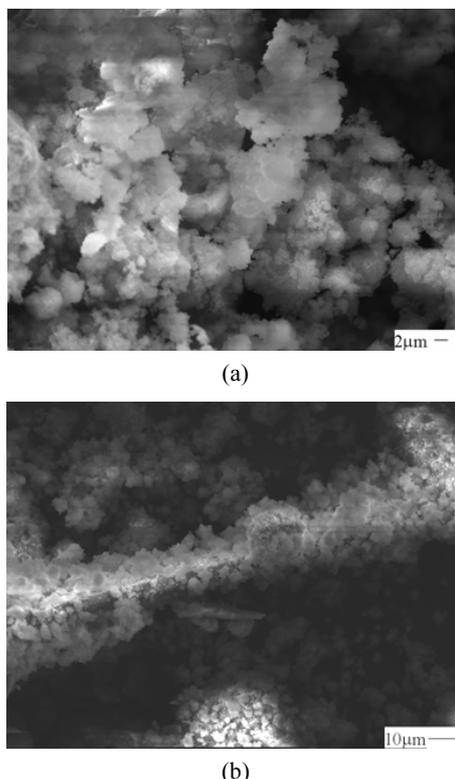


Fig. 11. Scanning of electron micrograph of P-Mg

4. Conclusions

According to the experimental test results, the following conclusions can be drawn ;

1. Dissolution of PPFW in H_2SO_4 solution increases with the increase of acid concentration and leaching temperature. Based on the findings of the kinetics study, it could be suggested that there is a series of steps in which more than one rate controlling process is involved in the observed kinetics. Approximately 81% of the extractable amount of Ni (84%) is extracted within the first minute of leaching process (1st stage) for 24 °C leaching temperature.

2. In the precipitation part, it was found out that the separation of dissolved metallic species from leach solution was effectively achieved. However, the selective separation of nickel, at the second stage of precipitation, was not obtained. This can be attributed to the resemblance of the precipitation pH of the dissolved metals such as Zn and Ni to the existing ion concentrations in solution after leaching.

3. The XRD and IR analysis of the final precipitate showed that P-Na could be characterized as a disordered α -Ni(OH) or as a blend of α and β -Ni(OH)₂, while P-Mg composed of mainly β -(Ni(OH)₂) phase and/or α -(Ni(OH)₂) phase.

The present study, which was directed to test the treatment and usability of electroplating plant waste as a secondary metal extraction, showed that the potential environmental impact of toxic metals in PPFW can be reduced by employing hydrometallurgical treatment method. However, a further beneficiation process such as solvent extraction has to be performed to selectively separate nickel from Ni- rich pre-concentrate.

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NIKELIAVIMO GAMYKLŲ ATLIEKŲ APDOROJIMAS IR NIKELIO IŠGRYVINIMAS

H. Kurama

Santrauka

Griežtėjant aplinkos apsaugos reikalavimams ir didėjant poreikiui taupyti mineralinius išteklius, siekiama plėtoti ekonomiškai perspektyvias rafinavimo technologijas. Ypač tai svarbu metalų apdirbimo pramonėje, nes didėja nuotekų šalinimo išlaidos. Išeitis būtų vertingų cheminių preparatų, susidarantių šiuose srautuose, pakartotinis panaudojimas ir perdirbimas.

Šiame darbe nikeliavimo gamyklos atliekų filtras buvo išnagrinėtas kaip alternatyvus šaltinis nikeliiui išgauti iš nikelio įsotintųjų nuosėdų. Apdorojimo testas atliktas taikant H_2SO_4 išplovimo metodą. Nustatyta, kad ištirpusių metalų, kaip antai: Ni, Cu, Zn, ir Cr, – kiekiai priklausė nuo plovimo trukmės, temperatūros ir rūgšties koncentracijos. Nors metalų junginiai beveik visai ištirpo per vieną plovimo valandą, iš proceso spartos ir didesnio ištirpusio Ni kiekio per pirmąją plovimo minutę (apytiksliai 81 % bendro išgauto Ni kiekio yra išgaunama pradiniu periodu esant 24 °C temperatūrai) galima spręsti, kad šių atliekų kaip Ni šaltinio panaudojimas yra pranašesnis, palyginti su Ni išgavimu iš natūralios rūdos. Atlikus kinetinių tyrimų Ni tirpumui nustatyti, paaiškėjo, kad proceso spartą lėmė cheminės ir difuzijos reakcijos. Filtruotasis tirpalas buvo nukreiptas nusodinti. Tai atlikta dviem etapais, kontroliuojant sąlygas, kai pH 4–5,5 ir vėliau pH 8,0 – atitinkamai išgaunant nuosėdas. Iš nusodinimo testo, atlikto su NaOH ar MgO, akivaizdu, kad beveik visi ištirpę nikelio jonai buvo išskirti iš tirpalo. Remiantis XRD ir IR analize, nustatyta, kad galutinės nuosėdos, susidarę naudojant NaOH, gali būti apibūdinamos kaip netvarkingas α -Ni(OH) arba kaip α ir β -Ni(OH)₂ mišinys, o naudojant MgO, nuosėdos susidarė iš β -Ni(OH)₂ ir/arba α -Ni(OH)₂ fazių.

Reikšminiai žodžiai: nikeliavimo atliekos, tvarkymas, Ni išgryninimas, šarmas, nusodinimas, perdirbimas.

ПЕРЕРАБОТКА ОТХОДОВ И ПОЛУЧЕНИЕ ЧИСТОГО НИКЕЛЯ НА ЗАВОДАХ ПО ОБРАБОТКЕ НИКЕЛЯ

Х. Курама

Резюме

В связи с ужесточением требований по охране окружающей среды и природных ресурсов заслуживает внимания вопрос о расширении применения экономически перспективных технологий по рафинированию. Это особенно касается металлургической промышленности в связи с увеличением расходов на удаление стоков, повторное применение и переработку ценных химических препаратов, остающихся в стоках. В статье описано исследование коммерческого фильтра по удалению отходов на заводе по обработке никеля в качестве альтернативного источника по получению никеля из осадков. Тест по обработке осадков, выполненный с применением метода вымывания H_2SO_4 , показал, что количество таких растворенных металлов, как Ni, Cu, Zn и Cr, зависит от времени вымывания, температуры и концентрации кислоты. Несмотря на то, что соединения металлов почти полностью растворились в течение одного часа вымывания, быстрое и большее количество растворенного в первую минуту вымывания Ni (приблизительно 81% от общего количества полученного Ni получают в начальный период при температуре 24 °C) показало, что применение этих отходов в качестве источника Ni имеет преимущество по сравнению с получением никеля из природной руды. Кинетическое исследование растворимости Ni показало, что скорость процесса обусловили как химические, так и диффузные реакции. После вымывания отфильтрованный раствор подвергался двухэтапному осаждению при pH 4–5,5 и позже pH 8,0. Тест по вымыванию NaOH или MgO показал, что почти все растворенные ионы никеля были выделены из раствора. На основании анализа XRD и IR установлено, что окончательный осадок, образовавшийся с применением NaOH, может быть охарактеризован как неупорядоченный α -Ni(OH) или как смесь α и β -Ni(OH)₂, в то время как при применении MgO осадки выпадали в фазах β -Ni(OH)₂ и/или α -Ni(OH)₂.

Ключевые слова: отходы производства по получению никеля, обработка, получение чистого никеля, щелочь, осаждение, переработка.

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