
NICKEL RECOVERY FROM ELECTROPLATING SLUDGE BY DIAPHRAGM ELECTROLYSIS PROCESS

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RINGKASAN : *Pemulihan nikel daripada enapcemar sadur elektrik dengan menggunakan proses 'diaphragm electrolysis' untuk pelupusan enapcemar toksik telah dikaji bertujuan mengekalkan punca logam berat dan mengguna semula logam dari pemulihan enapcemar tersebut. Proses ini dapat melenyapkan lebih kurang 90% kuantiti enapcemar mengikut isipadu, di mana dapat menjimatkan kos rawatan dan pelupusan. Kajian pada skala makmal telah dijalankan untuk menentukan keadaan optima dalam pemulihan nikel daripada enapcemar nikel dari kilang. Pada skala prototaip 110-liter, keadaan yang sama juga telah ditunjukkan iaitu kecekapan katod pada 90-100% keatas enapcemar yang sama. Produk telah diuji untuk ketulinannya. Penilaian ekonomi menunjukkan pemulangan yang baik terutamanya apabila kos pemulihan dan pembuangan diambilkira. Proses ini boleh juga digunakan untuk pemulihan logam berat yang lain seperti kuprum dan zink.*

ABSTRACT : The use of diaphragm electrolysis in the disposal of toxic sludge was studied with the aim of conserving heavy metal resources and re-utilizing valuable metals recovered from the sludge. This process could eliminate sludge quantity of more than 90 percent by volume, thereby saving on treatment and disposal costs. Bench-scale studies were carried out to determine the optimum conditions for good recovery of nickel from factory-segregated nickel sludge. A scale-up on a 110-litre prototype confirmed similar results of 90-100% cathode efficiencies using factory-segregated nickel sludge. The product was tested for its purity. Economic assessment was attempted which showed the viability of the process especially if the treatment and disposal costs were included. This process is applicable for recovery of other heavy metals such as copper and zinc.

KEYWORDS : Clean technology, diaphragm electrolysis, toxic sludge, electroplating, heavy metal recovery, re-utilization, economic assessment, sludge disposal, sludge treatment, disposal costs.

INTRODUCTION

The most recent survey (Rosnani, 1986) by the Department of Environment on 700 industries at the West Coast of Peninsular Malaysia revealed that 220,000 m³ toxic and hazardous wastes were generated. The metal-finishing industries were found to be the main contributors of these scheduled wastes. The small- and medium-sized industries generated acid and alkali wastes with toxic heavy metals which are usually discharged without any form of pre-treatment. Huge volumes of sludge were also generated by the larger factories, and were being accumulated in their premises for years awaiting solution for final disposal to approved landfill sites.

In recent years, the new concept of pollution prevention as compared to pollution control has become the dominating environmental policy in many developed countries which aim to reduce the amount and/or toxicity of pollutants being generated (Jacqueline, 1989). Clean technologies which aim to "produce better while polluting less" pose a real challenge to the industry.

The process of diaphragm electrolysis in the treatment of sludge has been investigated as a clean technology which greatly reduces the quantity of sludge and recycles heavy metals from sludge. This process as developed by Nawafune *et al.*, (1977), enables the recovery and re-utilization of heavy metals in sludges. Heavy metals precipitated as sludge are introduced into the anodic chambers of the cell containing the metal ions at a certain high concentration. An insoluble anode is inserted into each of the anodic chambers. The chambers are

separated by diaphragms from the cathodic chamber containing the metal ions at the same concentration. A cathode allowing easy exfoliation of the precipitated metal is inserted into the cathodic chamber for electrolysis (Figure 1).

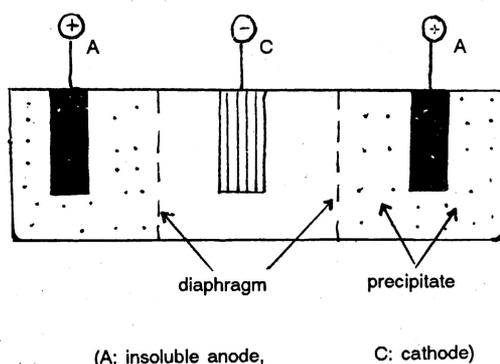
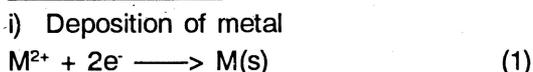


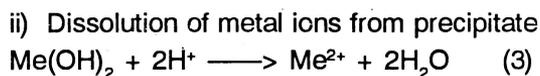
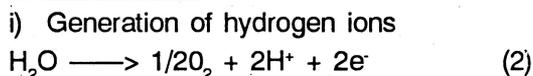
Figure 1. Diaphragm electrolyte cell

The reactions at the electrolytic cell are:

Cathode reaction:



Anode reaction:



At the cathodic chamber the metal ions are deposited as metal at the cathode [reaction (1)]. A metal with good properties can be precipitated at a high current efficiency even at a high current density if the metal ion concentration, pH of the catholyte and the bath temperature are properly controlled.

At the anodic chamber, the hydrogen ions generated in reaction (2) dissolve the sludge

to generate metal ions in reaction (3) and the metal ions move through the diaphragm into the cathodic chamber to increase the metal ions lost by precipitation at the cathode. The metal recovered can be re-used immediately as an anode for plating.

Preliminary studies have shown a very good recovery of heavy metals such as nickel, zinc and copper from simulated sludge with high cathode efficiencies of 90 to 100% (Chew and Mohd. Amin, 1990). This paper describes bench-scale studies and testing of a scale-up of the above process on a 110-litre prototype using factory-segregated nickel sludge. Economic assessments of the process were also carried out to show its viability. The heavy metals recovered were also tested for their purity.

METHODS

Bench-scale Studies

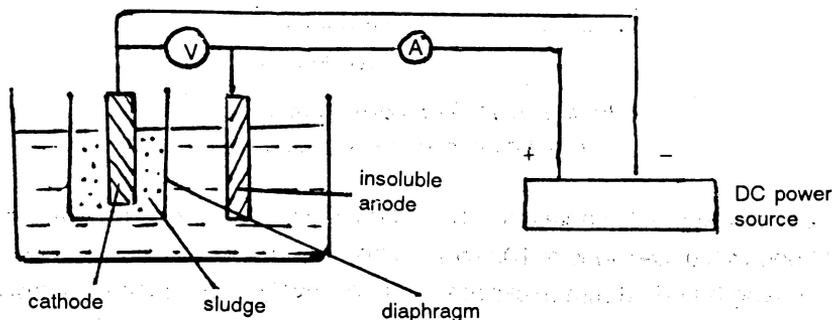
(Chew and Mohd. Amin, 1990)

Figure 2 shows the flow diagram of the electrolytic metal recovery cell. The electrolytic cell is a 2-litre beaker while the anodic chamber consists of a cotton cloth

bag of 200 ml capacity. The anode is a corrugated wire platinum-plated titanium mesh (11 x 2 cm), with a surface area of 0.44 dm². The cathode, however, is a copper sheet (4 x 6 cm) with a plated surface area of 0.24 - 0.32 dm² (one side insulated).

Electrolyte solutions of 1400 ml and 200 ml were added to the cathodic and anodic chambers respectively. The sludge was introduced into the anodic chamber periodically at varying intervals. Agitation using air bubbling was carried out to ensure uniform distribution of metal ions. The bath temperature was maintained with a magnetic heater/stirrer. The metal deposited and the pH at the anodic and cathodic chambers were measured at one-hour intervals. Metal in the catholyte was analysed using an atomic absorption spectrophotometer (Philips Pu 9200).

A series of bench-scale experiments were conducted to determine optimum conditions for electroplating. The effect of temperature, pH, current density using nickel sludge filter cake and simulated sludge, as well as different materials of anode were tested. The results obtained were then tested on the prototype.



(V: Voltmeter A: ammeter)

Figure 2. Flow diagram of electrolyte metal recovery cell

Prototype Trial Runs

A 110-litre capacity mobile prototype of the electrolytic metal recovery cell was locally fabricated (Figure 3). It consisted of two anodic compartments and one cathodic compartment. Two baskets which served as the anode compartments on both sides of the bath were placed inside the diaphragm bags. The sludge was then placed in the anode compartments so that it is separated from the cathode compartment. Insoluble anodes of 110 mm in width, 500 mm in length and 12 mm in thickness, were placed inside each compartment.

temperature was thermostatically controlled by a heater and water cooling system. Mixing of the electrolyte was by means of an air compressor. A cartridge membrane filter was also installed for continuous removal of contaminants in the electrolyte during operation. Air bubbling was employed to ensure uniform distribution of metal ions.

The electrolyte of 102 litres was initially added to the plating tank. Two insoluble anodes and one cathode which had been pre-treated (using standard plating procedures of degreasing, electro-degreasing, activation

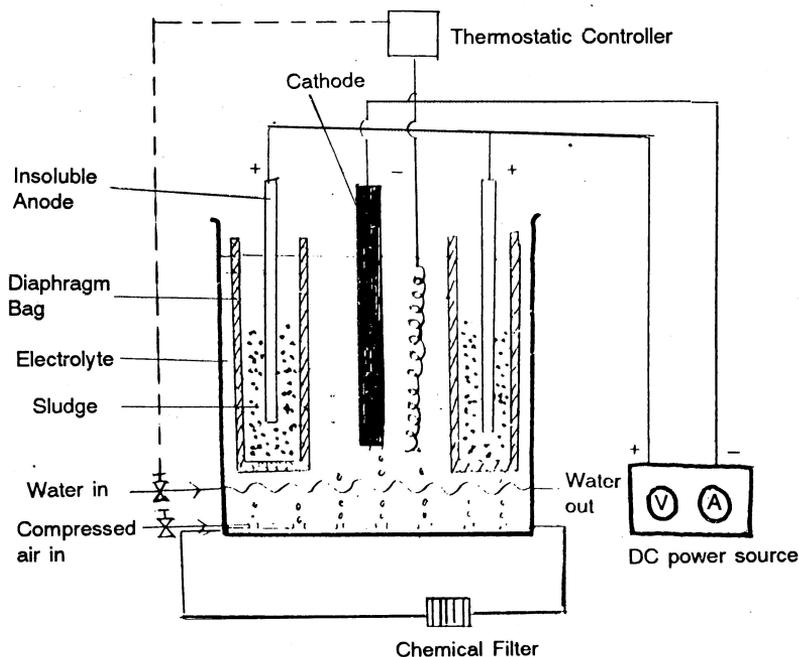


Figure 3. Metal recovery prototype
 [(V) Voltmeter, (A) Ammeter]

The cathodic compartment contained the mild steel cathode with dimensions of 100 mm width, 500 mm length and 18 mm thickness, in which nickel would be plated on. Direct current was supplied by a rectifier which also measured the current and voltage. The bath

and rinsing after each step) were inserted into the anodic and cathodic chambers respectively. The nickel hydroxide sludge filter cake was obtained from a factory. The sludge was introduced into the anodic chambers at a certain interval. The moisture content

of the sludge was initially determined. The flow circuit was setup with the following bath operating conditions for electrolysis:

Electrolyte : 240 g l⁻¹ NiSO₄
 30 g l⁻¹ H₃BO₄
 Current density : 4 A dm⁻²
 Bath temperature : 40 - 45°C

Current and voltage were recorded. The metal deposited was weighed and pH of the anodic and cathodic chambers were measured at one-hour intervals. The metal ion in the catholyte was analysed using an atomic absorption spectrophotometer.

RESULTS AND DISCUSSION

Initially, carbon anode was selected due to its low cost, and the effects of temperature and current density were investigated using simulated sludge. Table 1 shows the efficiencies of the recovery of nickel using an insoluble carbon anode on simulated sludge

Table 1. Recovery efficiencies of nickel using diaphragm electrolysis with insoluble carbon anode on simulated sludge at various bath temperatures and current densities

Plate	Current density (A dm ⁻²)	Bath temp (°C)	Efficiency (%)
NP 1	7.0	56	100
NP 2	4.2	45	91
NP 3	4.0	45	97
NP 7	2.0	30	52
NP 8	3.9	30	70
NP 9	5.0	30	83
NP 10	6.5	30	74

Notation : Sludge obtained by precipitation of factory rinsewater

at various bath temperatures and current densities. It was observed that 100% cathode efficiency could be obtained by plating at 56°C and 7 A dm⁻², but this high density might be difficult to achieve. Good plating was obtained at 45°C with an efficiency greater than 90% at 4 A dm⁻². At the lower temperature of 30°C and current density between 4 - 6 A dm⁻² cathode efficiency obtained was greater than 70%.

However, the carbon anode was observed to have split at the end of the experiment, and an alternative anode using platinum-titanium was used instead. A higher quality carbon anode may also be used in future since the carbon anode used in this experiment was found to be unsuitable for electroplating under the aforementioned bath operating conditions.

Comparison between Simulated and Factory Sludges

The recovery efficiencies of nickel using an insoluble platinum-titanium anode on simulated (30°C) and factory-segregated (45°C) sludge were compared (Table 2).

Table 2. Recovery efficiencies of nickel by diaphragm electrolysis using an insoluble platinum-titanium anode on simulated and factory-segregated sludge at various bath temperatures and current densities

Simulated sludge			Factory sludge	
Plate No.	Current density (A dm ⁻²)	Cathode efficiency (%) (Bath temp 30°C)	Plate No.	Cathode efficiency (%) (Bath temp 45°C)
NP 5	2	67	NP 11	85
NP 4	3.9	74	NP 12, 13	97 - 92
NP 6A	5	81	NP 14, 15	67 - 85
NP 6	6.5	79	NP 16	69

Table 2 indicates that for simulated sludge, efficiency increased with current density at 30°C. On the other hand, for the factory sludge at 45°C, its optimum efficiency occurred at 4 A dm⁻². It is possible to plate at 30°C using simulated sludge but efficiency is never greater than 80%. Generally, the results show that good plating can be obtained using factory sludge.

Effects of pH and Bath Concentration

Plating was found to be poor in some instances due to low electrolyte concentration (20 g l⁻¹) and low pH catholyte (<pH 4). This was rectified (Table 3), and good plating was achieved at longer period of electrolysis.

Table 3. Recovery of nickel by diaphragm electrolysis using factory sludge at 4 A dm⁻² and 45°C

pH _a	pH _c	Ni ²⁺ (ppm)	Cathode efficiency (%)	Comments
1.87– 5.8	3.8– 5.3	34 500– 59 000	95	23 h of operation
5.3– 6.1	5.8– 6.1	38 400	94	8 h. of operation
5.6– 6.2	6	42 450	97	4 h of operation

Notation : a = anolyte
c = catholyte

The optimum conditions for good plating of factory sludge with cathode efficiency greater than 95% were determined. These included a current density of 4 A dm⁻² at 45°C bath temperature and an electrolyte concentration of more than 180 g l⁻¹ nickel sulphate. The pH of anolyte and catholyte should preferably be maintained

above 5 although plating is also possible at pH 4.

Prototype Trial Runs.

The variations of metal ion concentration in the catholyte, cathode efficiency, pH of anolyte in the anodic chambers (A) and (B) and catholyte during the period of diaphragm electrolysis on some good platings are shown in Figures 4 - 10.

Initial Plating

Plating was initially carried out on P1. four kg of sludge (moisture content, 78%) was added into each of the anodic chambers. Figure 4 shows that pH of the catholyte remained stable around 4.87-5.16. When the pH of anolyte dropped to less than 4 in the anodic chamber, another 2 kg of sludge (moisture content, 25%) was added into each of the anodic chambers. The electrolyte concentration was quite stable throughout the run.

Good plating was obtained throughout the experiment with a cathode efficiency of 95.4%. However, peeling was observed at the bottom of the plate with some nickel metal deposited at the bottom of the bath. A considerable amount of sludge remained in the anodic chamber after the experiment.

No Addition of Sludge

Since there was a considerable amount of sludge in the bath, no sludge was added and plating was carried out on another new pre-treated plate P2. The plate was placed in a cotton bag to collect any nickel metal that had been plated and then detaching itself during the runs.

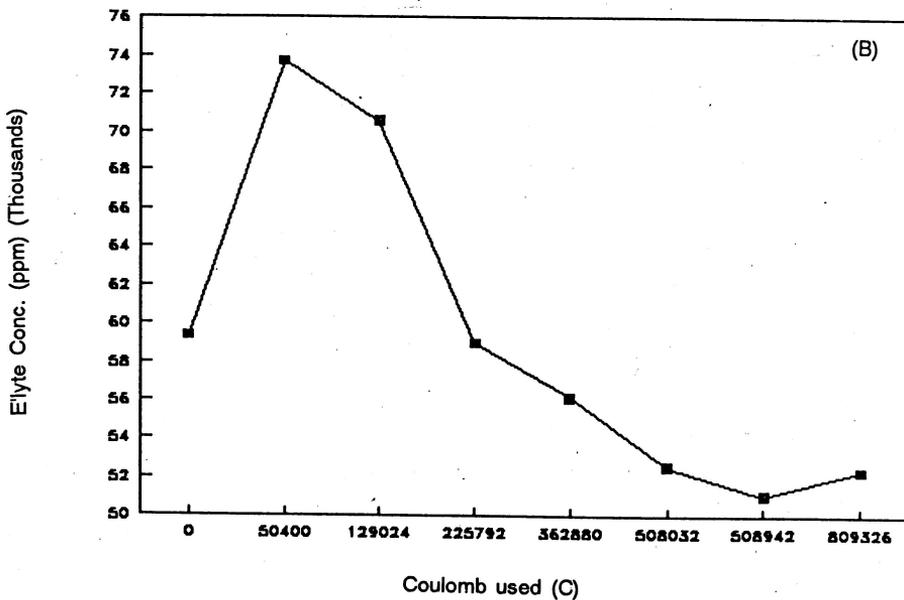
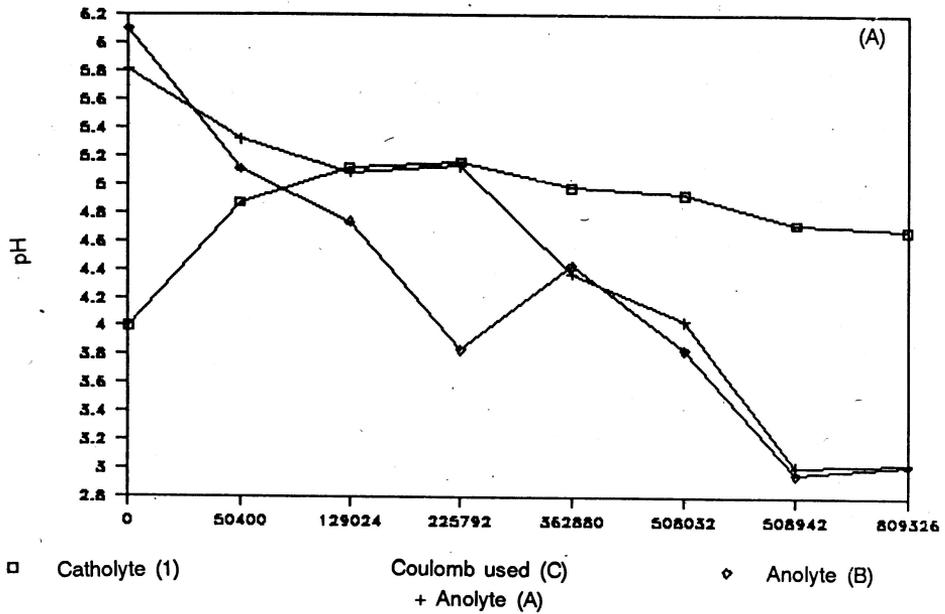


Figure 4. Electrolytic recovery of nickel (P1) from electroplating sludge
 (A) Variation in pH during electrolysis
 (B) Variation in catholyte concentration (nickel ion)

Figure 5 shows that the pH of catholyte remained fairly constant at around 5.7 for an electricity usage of 2.7×10^6 C and dropped thereafter to a pH of 5.4. pH of anolyte in both the chambers decreased with operation and but later increased. The nickel ion concentration of catholyte decreased with the time of operation (at 2.16×10^6 C) and later stabilized at around 57,000 ppm. Cathode efficiency, however increased from 85% to 98%.

Initial observation of the plating on the first day revealed a deposit with a smooth and non-stressed surface. Some peeling was also observed after a 3-hour operation. The peeling continued throughout the operation and good plating was observed in terms of smooth surface.

The experiment was repeated on plate P3. It was observed (Figure 6) that pH of catholyte inside the cotton bag (I) containing the cathode was different from that outside the cotton bag (O) and thus, measurements of both were noted. Figure 6 also indicated that the pH of the catholyte (I) was fairly constant around 3.3 whilst that of the catholyte (II) fluctuated slightly but remained quite stable around pH 4.0 - 4.7 and dropped slightly to 3.65 at the end of the experiment. Similarly, it was observed that pH of anolyte in chambers A and B fluctuated within the ranges of 4.76 - 6.44 and 4.12 - 5.75 respectively. Nickel ion catholyte concentration was maintained at around 75,000 ppm (range 71,450 - 79,550 ppm) and decreased to 57,750 ppm at the end of the experiment. Cathode efficiency was good at about 90 - 97% with bath temperature at 40 - 51°C.

Plating was good but not as lustrous as P2. This could be due to the pH of catholyte being lower than that in the previous run. Peeling was observed after a 9-hour operation together with some burning, after which the experiment was terminated.

pH Adjustments

An experiment was carried out on plate P4 where 1 kg of sludge was added into each chamber and no further sludge was administered due to its accumulation from previous runs. Figure 7 shows that pH of the anolyte in both chambers fluctuated within the range of 4.80 - 6.30. pH (O) and pH (I) of catholyte were initially at pH 4.00 and 3.50 which then decreased to pH 3.68 and 3.28 respectively, after an electricity usage of 6.2×10^5 C. Alkali was added to increase the pH (O) of catholyte to pH 4. Continued operation showed slight increases in pH but these values fell back to 3.81 and 2.98 respectively at the end of the experiment.

Catholyte concentration decreased with operation from 67,000 to 47,250 ppm. High plating efficiency at above 95%, and even over 100%, was caused by the burning on the plate.

It was observed that poor plating, with peeling and burning, was observed soon after a 2-hour operation. This was due to the low pH of the catholyte (less than 3). The addition of electrolyte was then made and plating was carried out on P5.

Figure 8 shows that pH (I) of the catholyte was initially at 5.58, and decreased gradually during electrolysis to 3.56. pH (O) of the catholyte was initially not measured

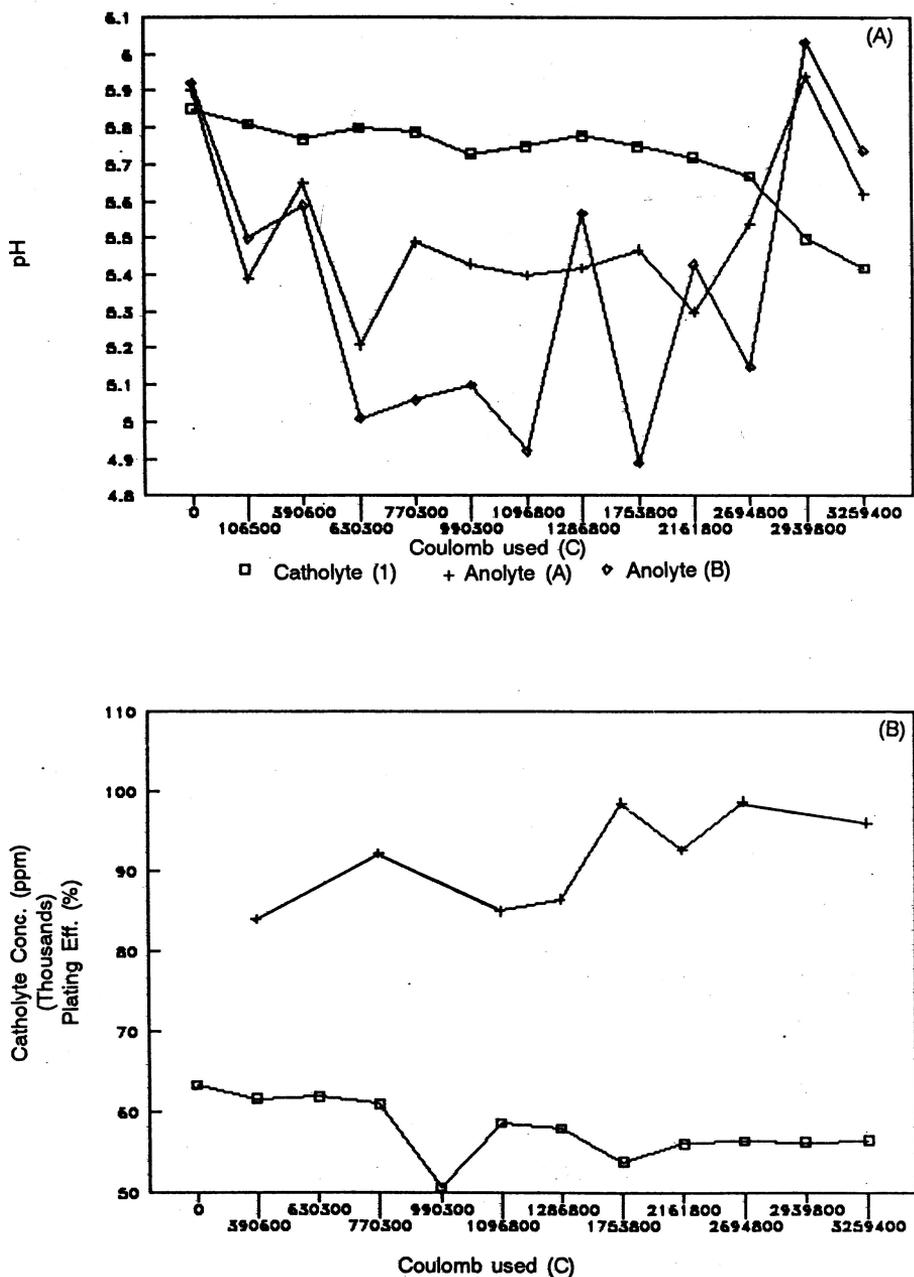


Figure 5. Electrolytic recovery of nickel (P2) from electroplating sludge (no addition of sludge)
 (A) Variation in pH during electrolysis
 (B) Variation in nickel ion concentration [□] and plating efficiencies [x] during electrolysis

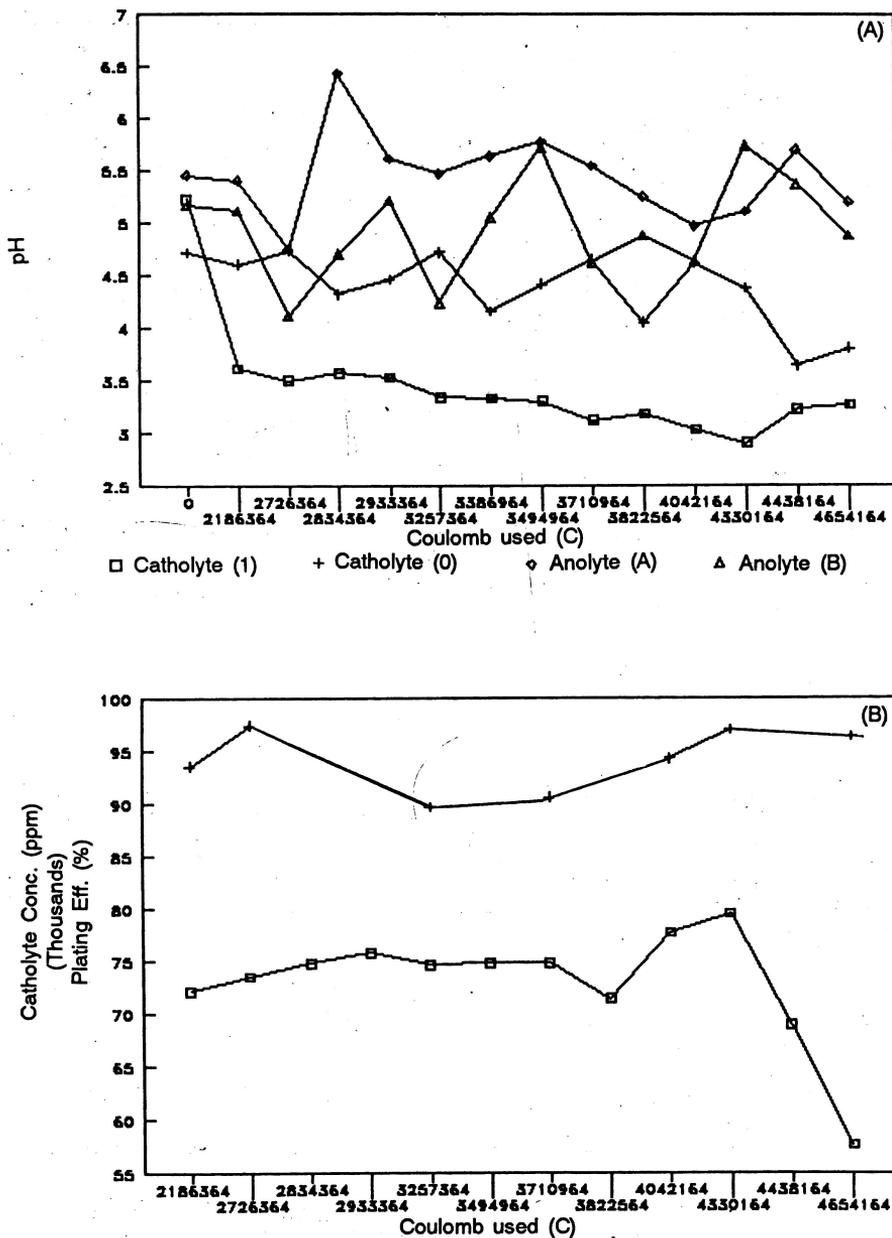


Figure 6. Electrolytic recovery of nickel (P3) from electroplating sludge (no addition of sludge)
 (A) Variation in pH during electrolysis
 (B) Variation in nickel ion concentration [□] and plating efficiencies [x] during electrolysis

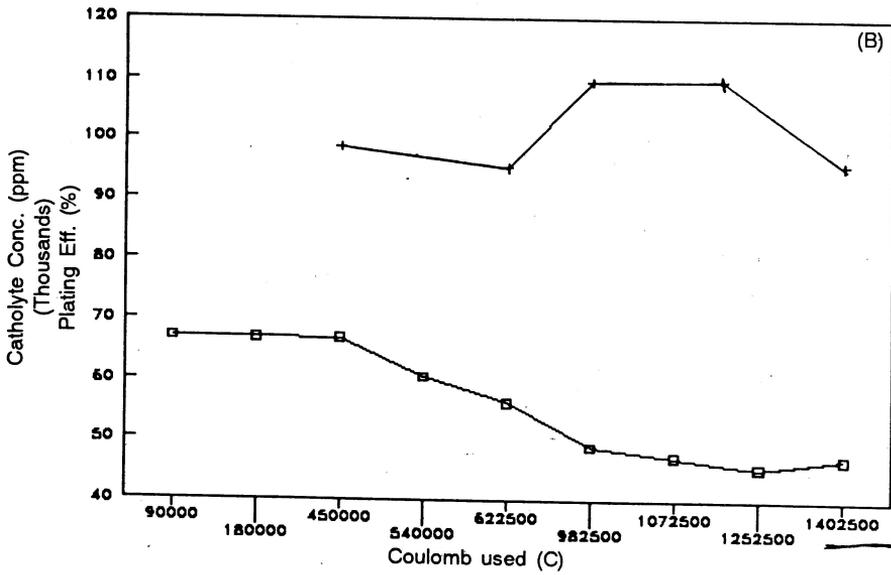
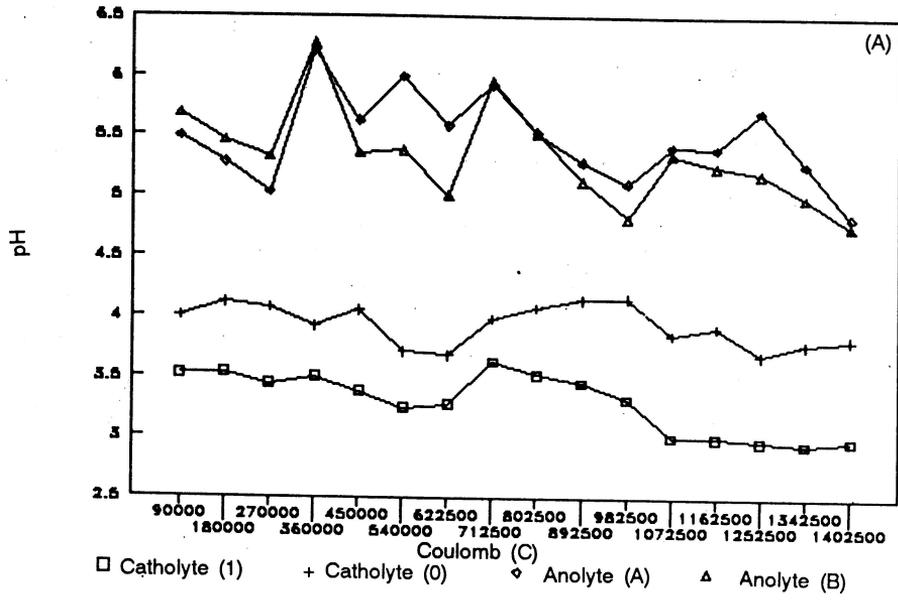


Figure 7. Electrolytic recovery of nickel (P4) from electroplating sludge (no addition of sludge)
 (A) Variation in pH during electrolysis
 (B) Variation in nickel ion concentration [□] and plating efficiencies [x] during electrolysis

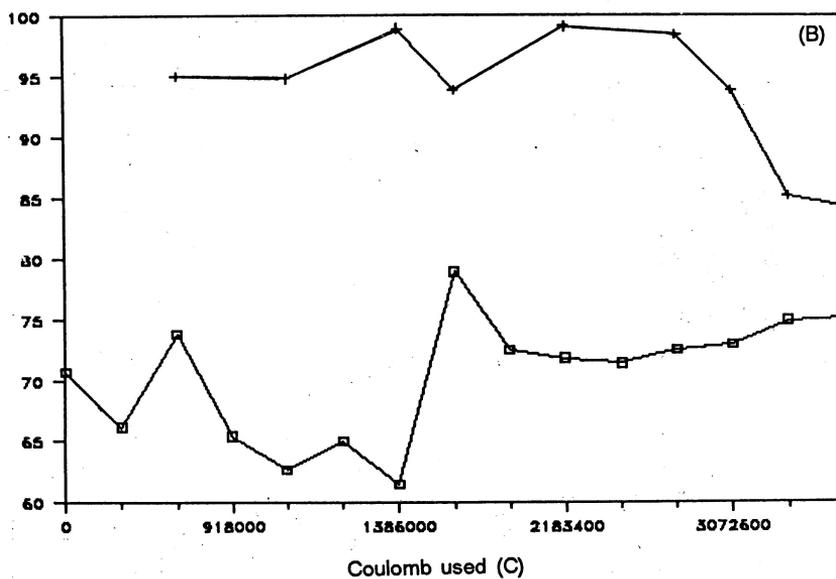
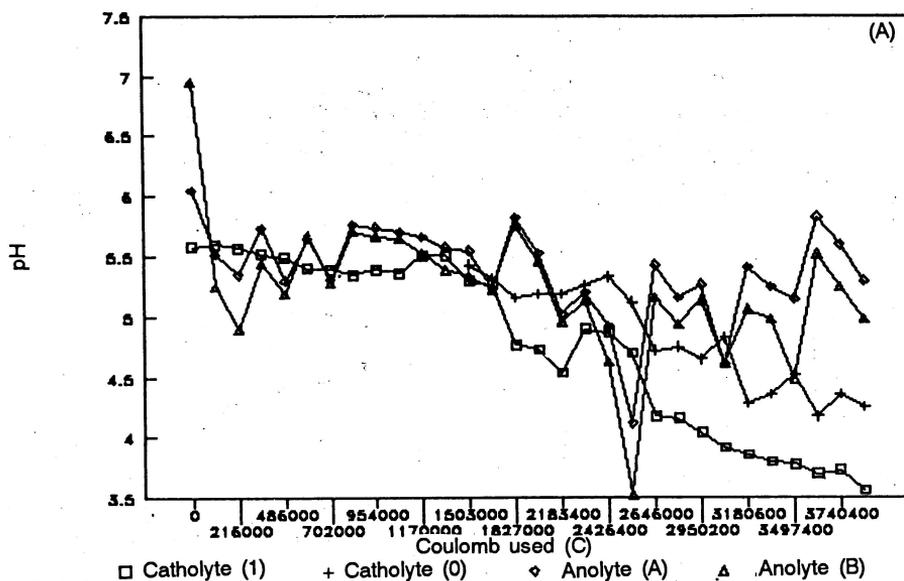


Figure 8. Electrolytic recovery of nickel (P5) from electroplating sludge
 (A) Variation in pH during electrolysis
 (B) Variation in nickel ion concentration [□] and plating efficiencies [x] during electrolysis

and when measured, it also showed a tendency to decrease gradually to pH 4.26 at the end of the experiment. Alkali was added periodically to maintain the pH. The pH of the anolyte in both chambers behaved similarly during the experiment, within the range of 4.12 - 6.05 and 3.53 - 6.95 respectively. The quantities of sludge added were 1.5 kg with moisture content of 22.10% and 4.5 kg with moisture content of 33.56% respectively. In general, it was observed that the nickel concentration was maintained within the range of 61,500 - 78,850 ppm. Cathode efficiencies were very good at above 94% but decreased to about 85% at lower pH values of the catholyte.

The addition of alkali to maintain the pH had therefore enabled the experiment to be carried out over a longer period of electrolysis with good cathode efficiency.

Sludge Addition at a Constant Rate

Sludge was added at a constant rate of 150 g h⁻¹ in order to maintain the concentration of electrolyte (on plate P6).

Figure 9 shows that pH (O) of catholyte was maintained fairly constant at around 4.45 - 5.05 whilst pH (I) of catholyte was maintained at above 4 for a period of 30 h with an electricity usage of 3.38 x 10⁶ C before it gradually decreased to 3.53. On the other hand, pH of the anolyte of (A) and (B) decreased throughout the run.

Initial cathode efficiency after the first 2 h was 91% after which peeling was observed. The plate was not removed from the bath thereafter to determine the cathode efficiency. Cathode efficiency was very good at 96%

as determined at the end of experiment and plating was good with smooth surface. The operation was carried out for the longest period of 47 h 40 min in 11 days with an electricity usage of 5.16 x 10⁶ C.

Continuous Operation

This run was carried out continuously for two days with an operation time of 44 h on plate P7. The plate was removed from the bath only for a short duration to examine the plating surface. Sludge was added periodically at a rate of 150 g h⁻¹ to each chamber. Figure 10 shows the pH (O) and pH (I) of the catholyte decreasing gradually from 4.24 to 2.44 and from 4.88 to 3.61 respectively. pH (A) and pH (B) of the anolyte was maintained within a range of 2.92 - 1.69 and 0.65 - 2.80 respectively. The catholyte concentration tended to decrease drastically from 82,740 ppm to 56,150 ppm at an electricity usage of 8.8 x 10⁵ C, after which it decreased gradually to 48,850 ppm towards the end of the experiment.

Cathode efficiency was still good at 86%. Peeling was only observed after 27 h at an electricity usage of 2.24 x 10⁶ C. Bristles were observed at all edges of the plate. At the end of the experiments, the electrolyte was analysed for impurities, and was found to contain ferrous at 150 ppm.

Optimum Operation

Table 4 shows the results compiled from the operational data where plating was carried out successfully.

In general, good plating could be carried out when pH (O) and pH (I) of the catholyte are

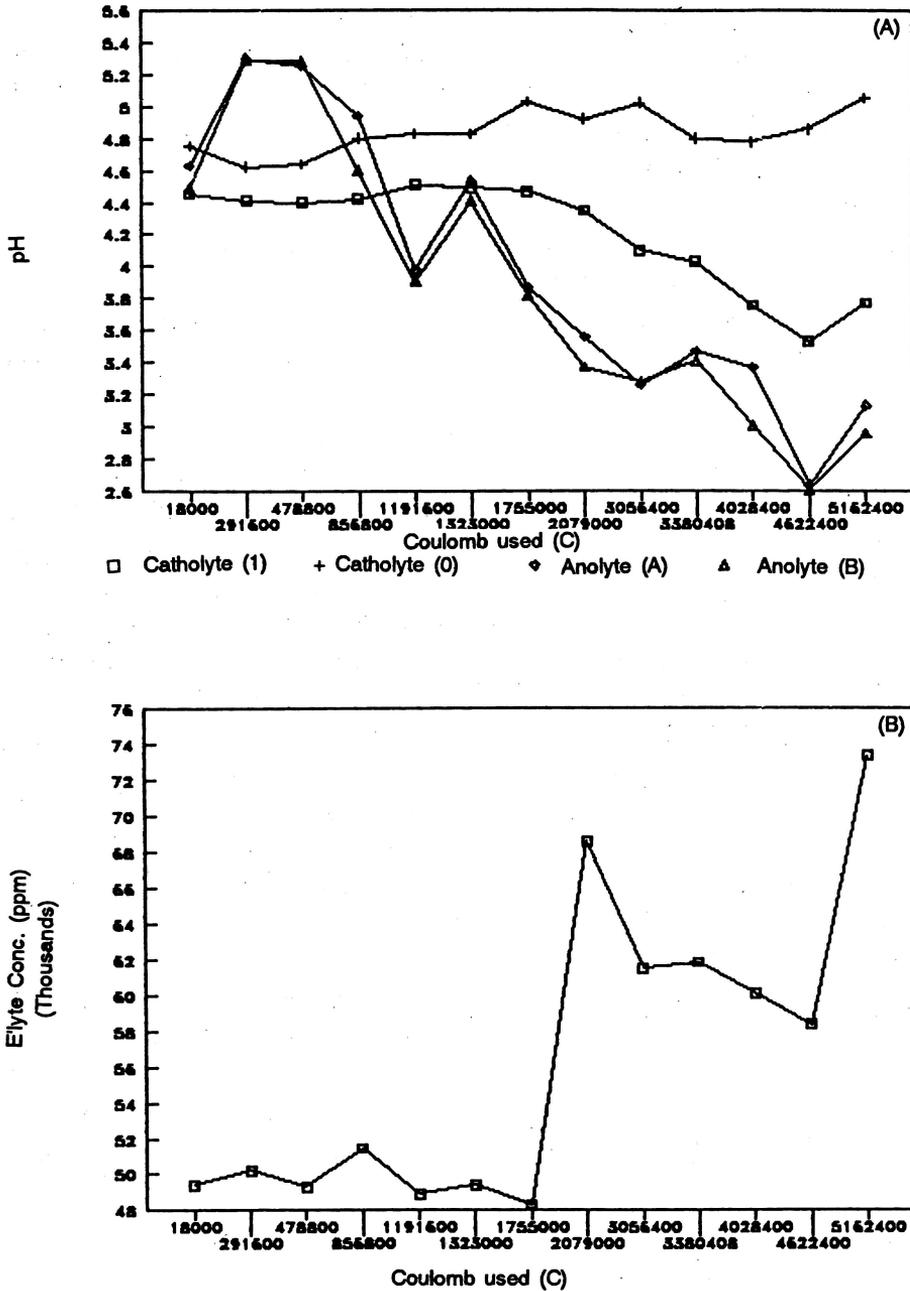


Figure 9. Electrolytic recovery of nickel (P6) from electroplating sludge (sludge addition at a constant level)
 (A) Variation in pH during electrolysis
 (B) Variation in nickel ion concentration [□] and plating efficiencies [x] during electrolysis

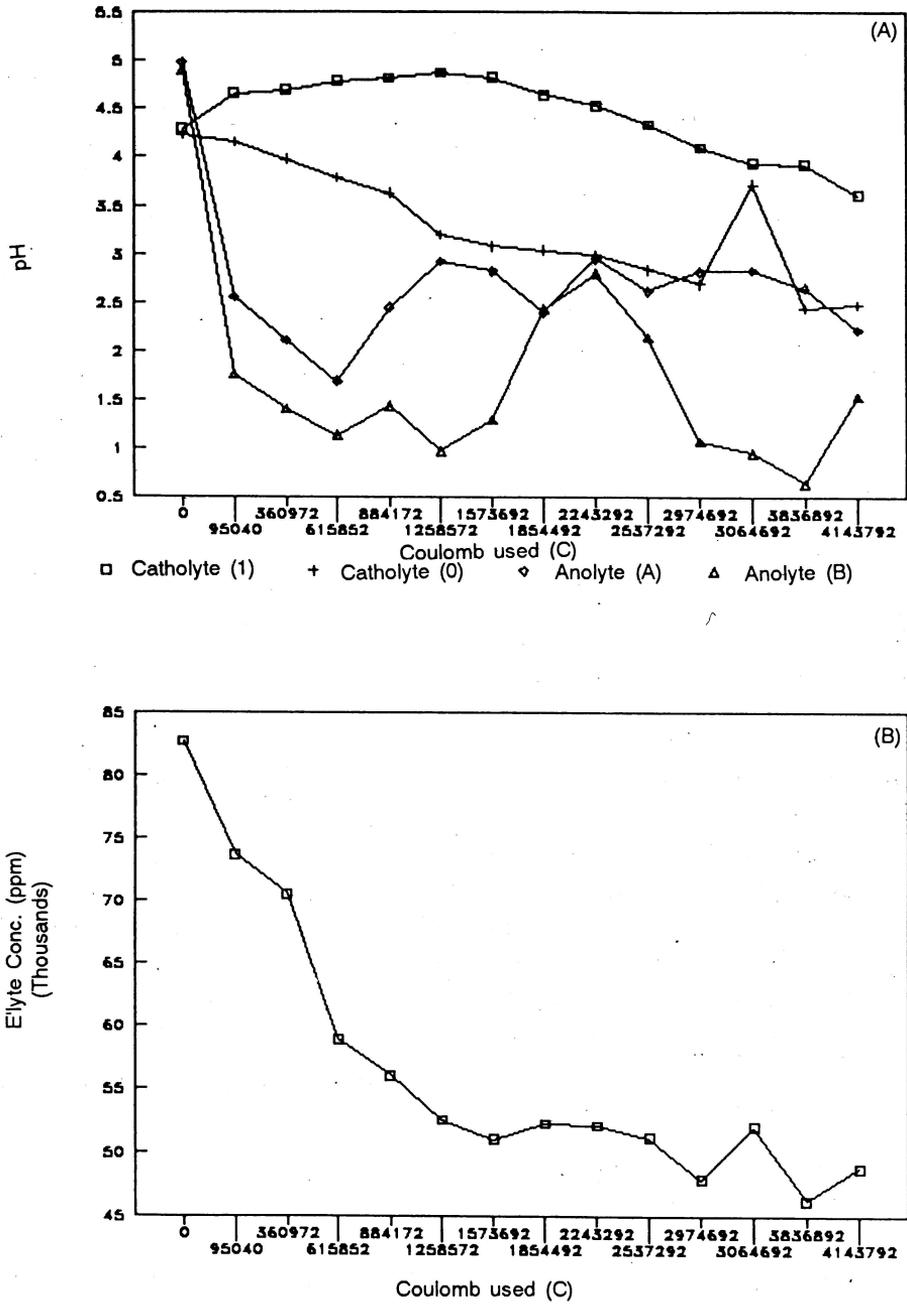


Figure 10. Electrolytic recovery of nickel (P7) from electroplating sludge (continuous operation)
 (A) Variation in pH during electrolysis
 (B) Variation in nickel ion concentration [□] during electrolysis

Table 4. Prototype trial runs on recovery of nickel from factory sludge

	Plate No.					
	P2	P3	P5	P6	P7	P8
pH _c catholyte		4.00-4.70	5.43-4.83	4.45-5.05	4.24-2.44	4.50-5.60
pH _c anolyte	5.40-5.70	3.30	5.58-3.92	>4.00	4.88-3.62	3.80-4.20
pH _a catholyte	5.30-6.00	4.76-6.44	6.05-4.12	2.92-1.69	5.30-2.60	4.63-6.27
pH _a anolyte		4.12-5.75	6.95-4.61	0.65-2.80		3.45-6.27
Efficiency	93-99	90-97	94-99	96	86	90-99
Concentration (x 1000 ppm)	57	75	62-79	>49	48-69	51-67
Quantity of electricity used (x 10 ⁶ C) hours of operation	3.259	4.654	3.917	5.162	4.144	4.567
Operation time (h)	31	25.68	36.27	47.83	33.12	41.52

above 4, although tolerable limits could be as low as 3.3. pH of the anolyte should preferably be maintained also at 4 although values as low as 1.7 could be tolerated. It was noted that for good plating it is more important to maintain the pH of catholyte than the pH of the anolyte. To maintain the pH of the anolyte, it is suggested that sludge be added whenever pH drops to less than 4.

The concentration of catholyte should be maintained preferably around 250 g l⁻¹ (i.e. 57 g l⁻¹ Ni²⁺) with a tolerable limit of 220 g l⁻¹ (49 g l⁻¹ Ni²⁺). To obtain good plating, the bath temperature should be operated preferably at 45°C and within the range of 40 - 50°C. Sludge (moisture content, 33%) should be added periodically to maintain a high concentration of NiSO₄ in the bath, preferably at the rate of 240 g l⁻¹ to each chamber. Cathode

efficiency obtained is expected to be greater than 90% for long periods of plating.

Sludge Residue

An interesting and important observation was the small amount of sludge of less than 10% by weight remaining at the bottom of the anodic compartment. This was due to the dissolution/deionisation of the sludge during the electrolysis process as described above.

Product Purity

A sample of the nickel deposit from the plated cathode was tested for its purity by two methods. Firstly, 1 g of nickel metal was added to 50 ml of 5 M nitric acid and heated in a beaker until all the metal dissolved. The heavy metals were analysed using an atomic absorption spectrophotometer. Nickel, iron, zinc, copper and chromium metal ions

were found to be 50,600 ppm, 69 ppm, 68 ppm, 7 ppm and undetected respectively. The impurities of iron, zinc, copper and chromium in the sample of the nickel deposit were less than 0.1%.

In the second method, electrolysis was carried out on the nickel deposit by using it as the anode whilst a pre-treated mild steel acted as the cathode. Bath conditions were maintained at 46°C with a catholytic pH of 4 and an electrolyte concentration of 240 g l⁻¹ NiSO₄ and 30 g l⁻¹ boric acid. The electrolyte was obtained from an electroplating company. Results are as shown in Table 5.

Plating efficiency was good with an average of 95% with smooth surface, no pitting, shining and was not stressed. It can be concluded that the nickel metal obtained from the sludge could therefore be re-used as anodes. Furthermore, the levels of impurities in the nickel deposit were low and therefore insignificant to affect the electroplating process.

Economic Assessment of Electrolytic Recovery Process

The cost of the system based on the prototype employed in this study is shown in Table 6.

Table 5. Nickel plating using plated cathode from diaphragm electrolysis as anode

Run	Period (min)	Bath temp (°C)	pH catholyte	Plating efficiencies (%)	Electrolyte concentration (ppm)
1	40	46	2.76 - 3.25	97.4	50,900 - 66,350
2	20	46	4.95 - 5.01	88.4	86,250 - 89,050
3	60	47	4.96 - 5.17	96.8	86,250 - 89,350
4	40	45	4.92 - 4.93	96.5	94,900 - 99,450

Table 6. Economic assessment of electrolytic recovery of nickel based on the 110-litre prototype (Recovery of 139 kg Ni/yr)

Cost (RM)		Unit price (RM)	
CAPITAL	33,400	<u>Neutralizing agents</u>	
YEARLY OPERATING EXPENSES:		Caustic soda	2.30/kg
(a) Power	300	H ₂ SO ₄	0.65/kg
(b) Chemical	1700	Polyfloc 20L	7.00/kg
(c) Neutralizing Chemicals	1216	Sulfuric acid	36.00/kg
	3 216	<u>Electric power</u>	0.18/kwh
GROSS PROFIT/YR	4 170	<u>Electrolyte</u>	
NET PROFIT/YR		Nickel sulphate	16.00/kg
(a) Recovery from sludge	2 170	Boric acid	5.00/kg
(b) Recovery from rinsewater	784	Alkali	55.30/kg
		<u>Capital cost</u>	
		- cost of equipment	33,000
		- cost of chemical	400

Profit obtained from the process was calculated by only considering the saleable price of nickel obtained against the operating costs. As such, if recovery was made only from sludge, the revenue would be RM 2170, whilst if recovery was from the rinsewater, the revenue would be RM 784, as the chemical cost of precipitating the heavy metals from the rinsewater has to be taken into consideration.

An economic viability assessment was also attempted for a factory incorporating the recovery system for its own generation of sludge which can recover 660 kg/yr of nickel (Table 7).

Table 7. Economic viability efficiency of recovery of nickel from sludge (660 kg/yr) in a factory

No.	Items	Costing (RM)	Total (RM)
1.	Capital (10% depreciation)	40,000/10	4000
2.	Operating expenses		
	2.1 Power @ \$0.18/kWh	1500	
	2.2 Electroplating chemicals	8500	10,000
	2.3 Neutralizing chemicals		6000
3.	Gross profit/yr (@ \$30/kg Ni)		19,800
4.	Net profit/yr		
	(a) Recovery from sludge		5800
	(b) Recovery from rinsewater		- 200

If the cost of neutralizing chemicals is not considered, there would be a net profit of about RM 6,000 per year. If neutralizing chemicals are included, there could be no profit obtained, but the treatment system would pay for itself. The power used to recover 1 kg of nickel was

estimated at 10.5 kWh kg⁻¹. The savings which could be obtained from the re-use of recovered nickel in the factory is shown as the gross profit of about RM 20,000 (Table 7).

It must be noted that the cost of sludge disposal has not been taken into consideration as there is no such treatment in Malaysia presently. However, if it is considered, this would favour the project economically as the company generating the waste will have to pay for the additional costs of sludge treatment and disposal to a landfill.

Therefore, in the long run, this project will bring good returns if implemented, and there will be no problems of sludge disposal in the factory.

CONCLUSIONS

The process of diaphragm-electrolysis was tested to the prototype stage in the recovery of substantial amounts of nickel metal, which can be re-used as raw material. The process eliminates sludge quantity of greater than 90% giving tremendous savings on sludge disposal and fixation costs.

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