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ECONOMIC ANALYSIS OF WASTE MINIMIZATION FOR ELECTROPLATING PLANTS

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ABSTRACT

The purpose of this study was to investigate the application of waste minimization technology to electroplating plants and to evaluate the economic aspects of such an application. Waste minimization in electroplating plants can be classified into two categories: recycling and source reduction. Generally, source reduction takes priority before the other and is the most economic tool for waste minimization. Reduction of spent cleaning solutions and drag-out minimization are two major tasks, in which 86% and 60%, respectively, of the plants reviewed were involved, while 74% of the electroplating plants utilized purification equipment to recycle raw materials. In the electroplating process, some heavy metals and rinse water can be recycled. Most of the plants that were investigated recycle the effluent water to the rinse process for further use. From the results of the case study, the cost of the equipment and the utilization rate of the facilities have greater influence on the net present value (NPV) than other factors. Therefore, if the cost or the utilization rate of the facilities varies, re-evaluation will be needed. © 1997 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Economic analysis; electroplating plant; recycling; source reduction; waste minimization.

INTRODUCTION

Because waste disposal regulations currently in effect in Taiwan have become more stringent, electroplating plants can no longer depend on end-of-pipe treatment as the sole method of pollution control of their wastewater and wastes, and must bear the burden of additional waste disposal costs. In-plant modification and development of more effective pollution control technology, directed toward decreasing waste output and increasing production and management efficiency, not only solve wastewater and waste treatment problems but also alleviate costs. Moreover, these changes improve safety in the plants and decrease the impact of plant wastes on the environment. Thus, industrial waste minimization has become the principal modification and environmental protection strategy in the electroplating industry. Its application as an effective and feasible waste minimization technology, however, requires both technical and economic analyses before actual implementation.

Industrial waste minimization technologies include source reduction, pollution prevention, recovery, and reuse. Application of technologies that decrease pollutant concentration per unit production, water use, and chemical dosage can directly improve efficiency. The impact on cost that these implementations will incur can be fully comprehended through economic analysis. Of the industrial waste minimization processes carried out in electroplating plants, source reduction is usually the lowest cost alternative, particularly for improving management and production processes. The costs incurred by recovery and reuse differ, however, depending upon the type of equipment used.

Economic analysis allows the unique features of each waste minimization technology to be exhibited, but the results for each plant differ according to the background and size of the plant. Because of this, the results of technological and economic analyses, though the analytical tools used are similar, are not mutual; the actual conditions of each plant are required for evaluation of the technology employed.

ELECTROPLATING PLANTS AND POLLUTION

There are 723 electroplating shops, the majority of which are small- to mid-size, presently in Taiwan. Of these establishments, a large portion electroplate chrome and nickel; a smaller share, copper and zinc; and a scant number, gold and silver. Electroplating shops cause pollution primarily by generating process wastewaters and metal sludges. Approximately 32-55 metric tons of wastewater are produced for every 100 metric tons of water used per day, or 231 l of wastewater are produced per m^2 of coated product. In Taiwan, the highest concentration of plants are in Taipei County, which contains 162 establishments, and Changhua County, which contains 138 establishments. In a study conducted by Ding (1991), it was found that pollution in agricultural areas of Changhua County was caused by untreated wastewater from electroplating plant. The average Cr concentration in the soil was 5.34 mg/kg dry wt. soil, but concentrations in several areas reached as high as 513 mg/kg dry wt. soil. For Ni, the average soil concentration was 11.42 mg/kg dry wt. soil and the highest was 242 mg/kg dry wt. soil.

Wastewater generated by electroplating shops can be categorized as follows: waste rinse water, spent cleaning solutions, and spilled and leaked plating solutions. In the traditional method of treating electroplating wastewater, Cr waste solutions are treated by reducing Cr(VI) to Cr^{3+}, cyanide wastes by oxidation of CN^- to CO_2 and N_2, and metal wastewater by chemical precipitation. Song *et al.* (1995) investigated traditional wastewater treatment methods and found that 58% of the electroplating shops in Taiwan were out of compliance with effluent standards. The discharged water quality of the shops and effluent standards are listed in Table 1. Song *et al.* (1995) further reported that the traditional form of treatment using chemical precipitation could not effectively remove soluble organics; as a result, 40% of the plants were unable to meet the 100 mg/L COD standard. Several plants, moreover, could not comply with effluent standards in their effort to cut costs by reducing chemical dosage, which created unfavorable chemical and pH conditions and thereby caused the incomplete precipitation of heavy metals.

Table 1. Discharged water quality and effluent standards

Item	COD	SS	CN^-	Cr(VI)	Ni	Cu	Zn	Fe	Pb
Range (mg/L)*	8-300	2-132	0.01-32.7	0.01-3.2	0.07-11.4	0-5.0	0.35-5.0	0.2-8.0	0.05-0.7
P_{50} (mg/L)**	70	20	0.24	0.20	0.58	0.85	2.07	1.90	0.17
Effluent standard	100	30	1.0	0.5	1.0	3.0	5.0	10	1.0

* Total of 50 plants reviewed.
**P_{50} is the value at which cumulative probability (with respect to the number of plants) is 50%.

Lin *et al.* (1993) found that the operating cost of treating electroplating wastewater is NT$ 200-1,500/NT$1 million total production cost; in relation to volume, each ton of wastewater treated costs NT$5.5-54.2. Song *et al.* (1995) calculated the cost of electricity and chemicals consumed during treatment to be NT$1.38-242.57/ton wastewater and the value of the cumulative probability at 50% to be NT$27.72/$m^3$, as shown in Table 2. Evaluation of minimization technology can be expressed by the ratio of waste generation rate to either product output rate or raw material consumption. Since highly-concentrated waste solutions from the plating tank, filter sludge in the plating tank, waste rinse water, and wastewater treatment sludge are the major sources of toxic wastes, evaluation can also be based on the change in quality or volume of these four types of wastes.

In a study conducted by Duke (1994), the waste reduction effectiveness of 33 electroplating shops in the San Francisco Bay area were investigated. Evaluation of the technology used in each facility was based on a total of 52 techniques in the following categories: process modifications, operation and maintenance (O & M) improvements, and in-plant pre-treatment. The results revealed that 33% of the shops achieved waste reduction efficiencies of 50% and above through process modifications, that efficiency ranged from 25% to 75% using O & M improvements, and that 60% of the shops showed greater than 50% efficiency by employing in-plant pre-treatment.

Table 2. Electroplating plant statistics and related data

Item	P_{50}
Volume of wastewater/unit production	232.31 L/m^2
Amount of sludge/unit production	141.80 g/m^2
Operating cost of wastewater treatment/unit production	NT$8.56/$m^2$
Cost of pollution control equipment/unit wastewater	NT$35,346/CMD
Operating cost of wastewater treatment/unit wastewater	NT$27.71/$m^3$

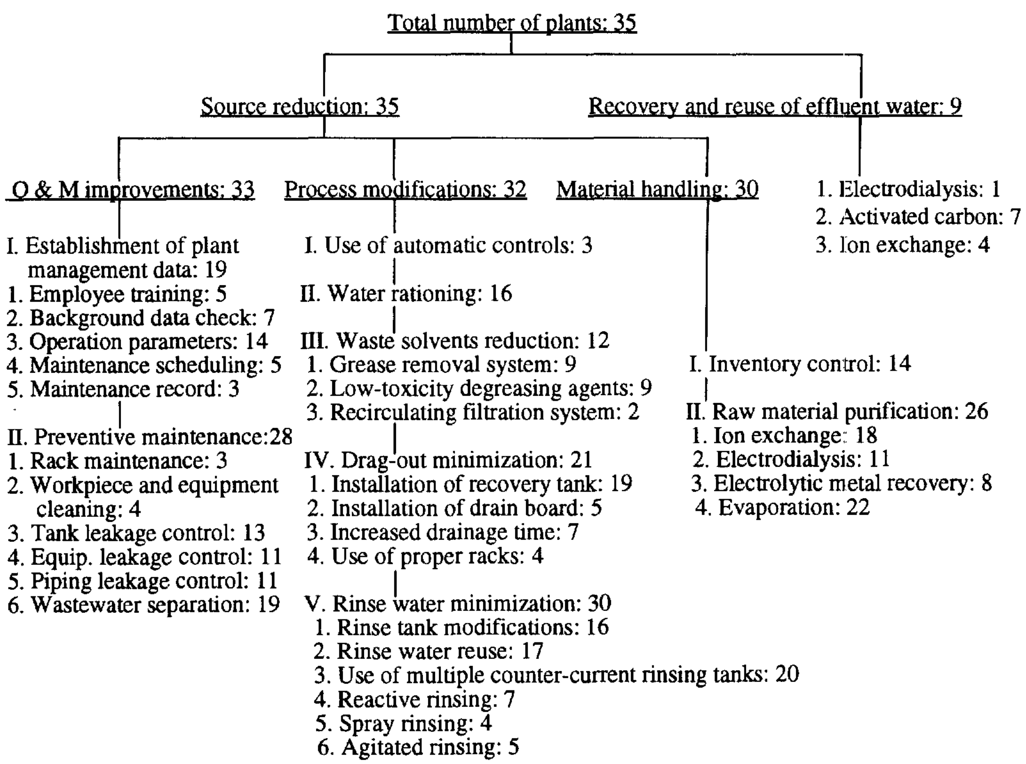

Figure 1. Summary of waste minimization techniques employed by electroplating plants in the study.

FEASIBLE WASTE MINIMIZATION TECHNOLOGIES

In this study, data from 35 electroplating plants in Taiwan practising industrial waste minimization were analyzed and the number of plants using each waste reduction technology was summarized (Fig. 1). According to the results, waste minimization primarily involves source reduction. Measures include proper cleaning, repair, and maintenance of equipment, drag-out minimization, and rinse water reduction. At the same time, the establishment of operation parameters, which lower raw material consumption and increase facility efficiency, help conserve materials.

Other source reduction measures are material management, which serves as an effective control of raw material consumption, purification or condensation to increase the lifetime of a plating solution, and rinse water reuse to reduce water consumption. Source reduction through raw material substitution and its effect on product quality requires further evaluation; therefore, none of the 35 plants studied employed this method.

Although the flowrate and characteristics of wastewater produced by each electroplating plant differ, it is obvious that drag-out and rinse waters are the major sources of waste and that the rinse processes account for the largest fraction of water consumed and wastewater generated. Thus, reducing drag-out and rinse water are the main tasks performed by waste minimization. Of the 35 plants reviewed, 30 (86%) practised rinse water reduction and 21 (60%) carried out drag-out minimization.

Solutions regenerated through impurity removal can be used for plating and making up solution that has evaporated or has been exhausted. Not only does this conserve materials but also reduces the wastewater treatment load. However, impurity removal requires the purchase of separate treatment facilities. Twenty-six (74%) plants utilized this type of waste minimization technique, and a portion of these were fitted with a variety of equipment because they treated for different compounds. The number of plants that recycled and reused effluent from end-of-pipe treatment totalled 9 (25.7%).

RESULTS OF CASE STUDY

Background data

From the 35 electroplating plants reviewed, the plant with the most complete background data was selected for economic analysis. Analysis was based on cost-effectiveness, which, in effect, is defined as choosing the best alternative with the lowest cost.

Raw materials consumed by the selected plant, which electroplates both nickel and chromium for industrial and decorative purposes, largely comprise degreasing agents, nickel sulfate, and chromic acid salts and are used to produce mostly umbrella frames and musical instrument components. The wastewater generated by this plant approximates 25 m^3/day, of which spent cleaning solution and waste rinse water account for 20 m^3/day and chromium and nickel wastes are responsible for 2.5 m^3/day each. The cost of the treatment facilities already in place is NT$2.1 million and chemical and power consumption per year total NT$480,000 and NT$96,000, respectively. Assuming that new facilities for recycling nickel plating solutions are to be set up, three alternatives available are discussed:

Plan 1. Drag-out is first sent to an electrolytic recovery tank for nickel recovery. Then, rinse water is purified using ion exchange resin and the waste solutions used to regenerate the resin are recovered in the electrolytic tank; the purified rinse water obtained is reused in the rinse process. Using this procedure, 106.4 kg of Ni could be recovered every three months. Moreover, the daily discharge of rinse water would decrease from 6,000 l to 24.5 l and the nickel concentration would drop to 10 mg/l.

Plan 2. By rinsing the workpiece in two still rinse baths after plating, plating bath constituents in drag-out can be purified and concentrated from the still rinse water through reverse osmosis and be returned to the plating bath. The filtered solution, moreover, can be reused as rinse water to replenish the second still tank. The initial cost for the reverse osmosis system and facilities in this plan total NT$250,000. Operation and maintenance costs, including power, maintenance, and membrane replacement, amount to approximately NT$80,000/yr. Based on an average of 5,000 hrs/yr, it is estimated that 0.45 kg of nickel sulfate could be recovered each hour; in monetary terms, if each kg is worth NT$59, the amount of metals recovered per year would result in savings of NT$132,000. The cost of sludge treatment and chemical agents for water treatment would also be reduced by a total of NT$72,000. Under this process, the nickel concentration of the residual solution is less than 10 mg/l.

Plan 3. The workpiece is moved from the plating tank to a still rinse tank to a two-stage counter-current rinsing system. Rinse water from the still tank is collected in a storage tank and then sent to an electrolytic tank, using a fluidized-bed electrolytic recovery system, to recover nickel. Initial set-up would cost NT$650,000 for the electrolytic metal recovery system and NT$150,000 for other equipment. Operation and maintenance fees are estimated at NT$21,060/yr for power, NT$33,750/yr for NaOH, which is used to control pH, and NT$60,000/yr for anode replacement, amounting to a total of NT$114,810/yr. After the system is in service, approximately 1.88 kg of nickel could be recovered per workday, saving the plant NT$168,800/yr. The residual Ni concentration is less than 10 mg/l.

Estimations of the cost and benefit of each alternative are shown in Table 3. Annual fixed cost is calculated by assuming that facility utilization has a 10-yr limit and that operation costs include chemicals, energy, and maintenance or replacement of used parts. Benefit is measured as reduced water consumption, lowered costs due to recovery and reuse of materials, and decreased spending on wastewater treatment chemicals and sludge disposal.

Table 3. Cost and benefit of each waste minimization plan

Cost and benefit*	Wastewater treatment	Ion exchange and electrodialysis	Reverse osmosis	Electrolytic metal recovery
Initial set-up cost	$2,100,000	$650,000	$250,000	$800,000
Annual operation cost	$576,000	$12,000	$80,000	$114,810
Savings of recovered metal	$0	$24,628	$132,000	$168,800
Reduction in treatment cost	$0	$6,177	$72,500	$56,500
Total benefit	$0	$30,805	$204,500	$225,300

* Wastewater flowrate = 25 CMD

Economic analysis

The results of the analysis are shown in Table 4. Plan 1 (ion exchange and electrodialysis), assuming a discount rate of 8%, equipment life span of 10 years, and 5 years depreciation, has a negative net present value (-$1,042,869). It reveals that investment is greater than profit, thereby rendering Plan 1 a non-profitable investment plan. Analysis of Plan 3 (electrolytic metal recovery) provides similar results. Plan 2, in contrast, with a net present value of NT$385,770 and an internal rate-of-return of 31.76%, which is greater than the assumed discount rate (8%), is a remunerative waste minimization plan. Plants generating a wastewater flowrate of 25 m^3/day, therefore, should employ Plan 2 for waste reduction.

Table 4. Economic analysis of each waste minimization plan*

Net present value (NPV)	Ion exchange and electrodialysis	-$1,042,869
	Reverse osmosis	$385,770
	Electrolytic metal recovery	-$697,437
Internal rate-of-return (IRR)	Ion exchange and electrodialysis	-
	Reverse osmosis	31.67%
	Electrolytic metal recovery	-8.42%
Capital recovery time (CRT)	Ion exchange and electrodialysis	-
	Reverse osmosis	4.06 yrs
	Electrolytic metal recovery	-

* Wastewater flowrate = 25 CMD

Sensitivity analysis

Sensitivity analyses of the equipment cost, discount rate, and utilization rate of facilities were conducted to determine their effects on the economic analysis results of each plan (Tables 5-7).

According to Table 5, when the cost of the equipment is increased or cut by 30%, the net present value of Plan 2 (reverse osmosis) changes by -34.97% to +34.97%, respectively; the fluctuation is even greater for Plan 3 (-61.89% to +61.89%). An increase in equipment cost causes the internal rate-of-return to gradually decrease and the capital recovery time to increase.

Table 5. Sensitivity analysis results of the equipment cost

		Change percentage of the equipment cost						
Plan*	Indicator	-30%	-20%	-10%	0	+10%	+20%	+30%
Plan 1	NPV	-$692,154	-$809,059	-$925,964	-$1,042,869	-$1,159,774	-$1,276,680	-$1,393,585
	NPV change(%)	33.63	22.42	11.21	0	-11.21	-22.42	-33.63
Plan 2	IRR(%)	52.52	43.86	37.10	31.67	27.20	23.42	20.19
	NPV	$520,660	$475,697	$430,733	$385,770	$340,806	$295,843	$250,879
	NPV change(%)	34.97	23.31	11.66	0	-11.66	-23.31	-34.97
	CRT(yr)	2.22	2.74	3.34	4.06	4.95	5.54	6.12
Plan 3	IRR(%)	-0.34	-3.53	-6.00	-8.42	-10.35	-	-
	NPV	-$265,787	-$409,670	-$554,554	-$697,437	-$841,320	-$985,203	-$1,129,087
	NPV change(%)	61.89	41.26	20.49	0	-20.63	-41.26	-61.89

* Wastewater flowrate = 25 CMD

The effect of discount rate change on both net present value and capital recovery period is greater for Plan 2 than for the other plans (Table 6). When the discount rate is increased, net present value decreases, capital recovery time increases, and internal rate-of-return remains the same.

As shown in Table 7, a change in the utilization rate of facilities of a plan directly affects its profitability. Thus, the higher the utilization rate of facilities, the greater the profit. In addition, both net present value and internal rate-of-return increase and capital recovery time shortens.

Table 6. Sensitivity analysis results of the discount rate

Plan*	Indicator	Discount rate						
		5.60%	6.40%	7.20%	8.00%	8.80%	9.60%	10.40%
Plan 1	NPV	-$1,062,550	-$1,055,879	-$1,049,317	-$1,042,869	-$1,036,536	-$1,030,319	-$1,024,218
	NPV change(%)	-1.89	-1.25	-0.62	0	0.61	1.20	1.79
Plan 2	IRR(%)	31.67	31.67	31.67	31.67	31.67	31.67	31.67
	NPV	$471,019	$440,867	$412,492	$385,770	$360,585	$336,831	$314,410
	NPV change(%)	22.10	14.28	6.93	0	-6.53	-12.69	-18.50
	CRT(yr)	3.82	3.90	3.98	4.06	4.16	4.25	4.35
Plan 3	IRR(%)	-8.42	-8.42	-8.42	-8.42	-8.42	-8.42	-8.42
	NPV	-$652,524	-$668,683	-$683,622	-$697,437	-$710,215	-$722,037	-$732,976
	NPV change(%)	6.44	4.12	1.98	0	-1.83	-3.53	-5.10

*Wastewater flowrate = 25 CMD

Table 7. Sensitivity analysis results of the utilization rate of facilities

Plan*	Indicator	Change percentage of the utilization rate of facilities						
		-30%	-20%	-10%	0	+10%	+20%	+30%
Plan 1	NPV	-$1,104,880	-$1,084,210	-$1,063,540	-$1,042,869	-$1,022,199	-$1,001,528	-$980,858
	NPV change(%)	-5.95	-3.96	-1.98	0	1.98	3.96	5.95
Plan 2	IRR(%)	6.26	15.16	23.54	31.67	36.39	47.67	55.64
	NPV	-$26,894	$111,327	$248,548	$385,770	$522,991	$660,212	$797,433
	NPV change(%)	-106.97	-71.14	-35.57	0	35.57	71.14	106.71
	CRT(yr)	-	7.32	5.52	4.06	3.08	2.48	2.07
Plan 3	IRR(%)	-	-	-	-8.42	-4.39	-0.70	2.76
	NPV	-$1,150,971	-$999,793	-$848,615	-$697,437	-$546,259	-$395,080	-$243,902
	NPV change(%)	-65.03	-43.35	-21.68	0	21.68	43.35	65.03

* Wastewater flowrate = 25 CMD

CONCLUSION

Different analytical factors provide a variant basis of consideration for each electroplating plant. For instance, net present value and internal rate-of-return can be used to determine project profitability; and although capital recovery time does not take discount value into account, it can be used to assess the risk and capital recovery period. Depending on the characteristics of each plant, these factors are employed for choosing the appropriate minimization plan. Small-sized electroplating shops with less capital, for example, could choose a plan based on capital recovery time, which has lower risk involved. For plants with more capital, net present value could be the deciding factor, choosing a plan that would be the most economically effective as well as obtaining the greatest profit.

The results of the sensitivity analysis revealed that equipment cost and utilization efficiency have the greatest influence on net present value. A change in either factor while deciding upon a plan thus requires re-evaluation. Of all the actual and assumed waste minimization plans mentioned in the study, reverse osmosis is the best reduction plan under the assumed conditions. However, because actual plant conditions may differ from the assumed conditions, individual analysis of each plant is required.

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