PRODUCTIVITY

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Green Productivity Audit Approach for Small-Scale Electroplating Industries: APO Demonstration Factory Project

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INTRODUCTION

This case study was undertaken as a demonstration project on pollution prevention and control in a small-scale electroplating enterprise. The study was conducted in a small-scale electroplating shop in Bangkok. A set of simple options like plant layout replanning, better housekeeping techniques, and product flow sequencing, and detailed options like efficient dragout recovery using spray rinsing techniques and in-house deionized (DI) water production were implemented. Better working conditions and increased production quality and efficiency were observed due to the simple modifications. Quantitative data obtained from audits before and after the modifications revealed substantial material and cost savings. Annual material savings in the range of 198,600 baht were achieved. Annual savings of 81,850 baht were obtained as a result of in-house DI water production using a membrane filtration system. The combined outcome of the modifications was a reduction in the load on the end-of-pipe treatment due to increased closed looping and recycling of materials.

The electroplating industry by virtue of its usage of toxic heavy metals poses a major problem in the treatment and disposal of the wastewater generated. The wastewater from a typical electroplating enterprise contains toxic metals like copper, nickel, chromium, etc., which if discharged into natural streams or water bodies can result in the destruction of their environmental balance and a health hazard for human beings and animals drinking from them.

This APO Demonstration Factory/Farm Project was carried out in one small-scale electroplating enterprise in Bangkok, Bangplee Chromium. The primary objectives were to conduct a material balance survey, identify potential areas of material losses, quantify the losses, and suggest process or equipment modifications to rectify the situation. The plating shop selected plates clothing irons and rice cookers. A rack system is used for hanging the workpieces. Four irons and one rice cooker can be accommodated on the rack. Rice cookers are plated in the first half of the day and irons in the second half. Bangplee Chromium employs 22 full-time workers who handle the complete plating process from buffing to polishing and packing. The working schedule is eight hours per day, 25 days per month, 300 days per year. The audit program implementation was carried out in four stages:

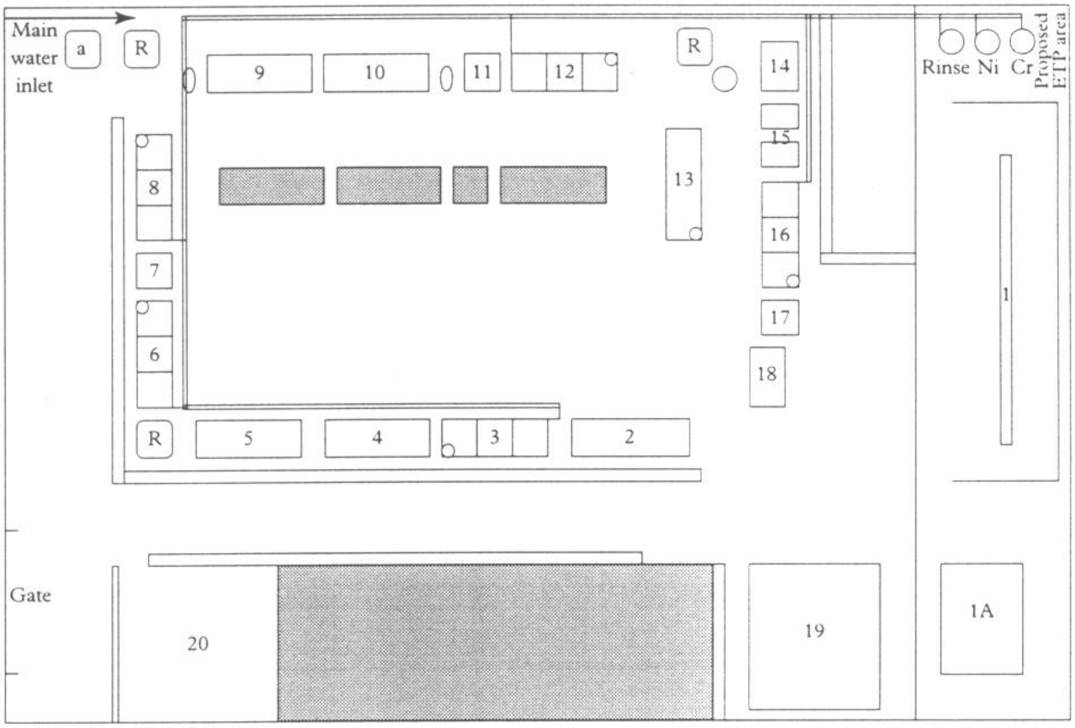
1) Stage 1 was the preassessment which involved preauditing, i.e., recording observations at "zero level" in the enterprise without any modifications.
2) In stage 2, based on the results of preauditing, recommendations were made in three phases, the first of which involved preliminary modifications like layout replanning, time and motion study to identify and eliminate bottlenecks in the operation, and other housekeeping techniques. The second phase comprised identification of rinsing activities, determining the quantity and quality of wastewater generated, and making detailed process and equipment modifications required to minimize waste generation and maximize the product quality. The third phase recommended future operational details, wastewater treatment options, etc.
3) Stage 3 involved implementation of the recommendations from phases 1 and 2 in the second stage.
4) Stage 4 involved postauditing to evaluate the degree of waste minimization and process improvement achieved in the implementation phase.

The production sequence in Bangplee Chromium starts with surface preparation, i.e., buffing of workpieces, alkaline soak cleaning, alkaline electrocleaning, and acid rinsing. All these processes remove oils and impurities and coat a uniform basic metal (e.g., steel) on the workplace surface. Then electroplating is carried out, which includes semibright and bright nickel plating and a dragout recovery and rinse before chromium plating. The chromium plating tank is also followed by a dragout recovery tank. Polishing and inspection are the next steps, which consist of inspection of plating quality, drying (either air or oven drying), and polishing to achieve a perfect surface finish. This step is necessary to maintain plating quality control. Faulty material is plated again after electrostripping the existing deposition. Countercurrent rinsing with clean water is done after each of the above steps to provide better surface cleaning for the next operation.

FINDINGS IN THE PREAUDIT STAGE

Several problems were identified during the preauditing phase. The general layout of the individual tanks in the plating area was not designed for the smooth flow of raw materials, water, and workpieces. The original layout of the plating shop is shown

Figure 1. Original plant layout.



- Filters
- Piping
- Water taps
- Future expansion

1. Buffing/polishing section, 10 × 7 m
1A. Buffing inspection
2. Soak tanks, 3 units, 60 × 60 × 60 cm
3. Soak rinse, 3 units, 80 × 80 × 110 cm
4. Anodic elctroclean, 1 unit, 240 × 80 × 110 cm
5. Cathodic electroclean, 1 unit, 240 × 80 × 110 cm
6. Electroclean rinse, 3 units, 80 × 80 × 110 cm
7. Acid dip, 1 unit, 80 × 80 × 110 cm
8. Acid rinse, 3 units, 80 × 80 × 110 cm
9. Semi bright nickel, 1 unit, 300 × 120 × 110 cm
10. Bright nickel, 1 unit, 300 × 120 × 110 cm
11. Nickel dragout recovery, 1 unit, 100 × 120 × 110 cm
12. Nickel rinse, 3 units, 80 × 80 × 110 cm
13. Intermediate rinse, 1 unit, 240 × 80 × 110 cm
14. Chromium bath, 1 unit, 100 × 80 × 110 cm
15. Chromium dragout recovery, 2 units, 80 × 80 × 110 cm
16. Chromium rinse, 3 units, 80 × 80 × 110 cm
17. Final rinse, 1 unit, 100 × 60 × 110 cm
18. Drying section
19. Inspection/raw material
20. Storeroom

in Figure 1. The tanks were widely spaced and improperly placed, leading to considerable dragout and spillage losses. The spillover drained into floor-level openings leading to the final discharge point beyond the premises of the plating shop. Concentrated solution was lost due to this practice. Certain accessories such as the filter for continuous cleaning of the nickel plating solution were placed between the tanks, requiring extra space for workpiece movement and draining the dragout to the ground.

The dragout losses observed during workpiece transition were calculated as follows. Based on the average daily number of workpieces, the amount of water lost per day for irons was 675 × 25 ml = 17 liters and for rice cookers was 108 × 1 liter = 108 liters. The total amount of water spilled daily during workpiece transition between two successive widely spaced tanks was 125 liters.

Time and motion or product sequencing studies revealed that bottlenecks existed at certain locations such as the cathodic electroclean and nickel plating tanks, meaning that workpieces had to wait in the previous tank for times ranging from 2 to 8 minutes. This resulted in reduced production potential and labor capacity. The process control (such as movement of workpieces, opening of rinse water taps, plating time, etc.) was manual and judgment based. There were no scientific means to measure the quality of the products, other than visual observation. This resulted in improper water and raw material consumption and inefficient production. Work allotment and distribution systems were not designed for reducing man-hours of operation.

Rinsing calculations indicated that the rinse rates were lower than those required for ideal rinsing. In spite of the lower rinse water rates observed, intermittent water usage (sometimes the taps were left open when workpieces were not being rinsed) increased the maximum water consumption on certain days. The tap water used in the dragout recovery tanks was found to have high conductivity of about 2000 µsec/cm. Thus the recycling of this recovery tank solution added salts and impurities to the plating tanks, which affected the plating quality. A summary of the flow and concentrations of metals in the rinse water is presented in Table 1.

Table 1. Summary of observed flows and metal concentrations.

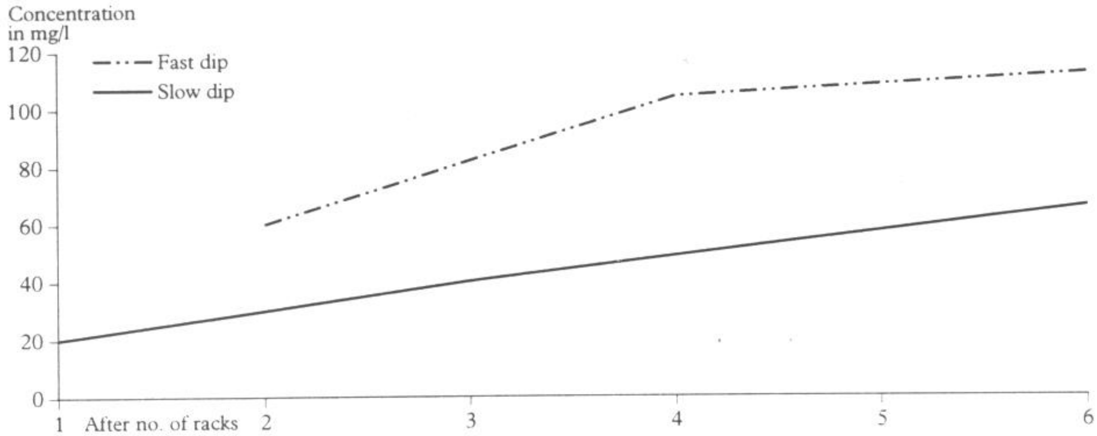
Description	Nickel Plating Stream	Chromium Plating Stream	Other Rinse Water
Quantity of rinse wastewater (m^3/month)	10.5	20.5	11.25
Quantity of dragout spillover lost to floor drain (m^3/month)	3.12	0[a]	–
Total quantity (m^3/month)	13.62	20.5	11.25
Metal concentration (mg/l)	3,495	2,000[a]	–

[a]No substantial spillover to the ground was observed from the chromium dragout tank due to the proximity of the recovery and rinse tanks.

Since the method of dipping the racks was manual, workers sometimes carried out the dipping fast and carelessly, resulting in larger dragover and subsequent loss from the tanks. Higher dragout was observed for rice cookers because of the curved shape which retains the solution on edges and crevices. Experiments conducted on rising or dipping during the audit indicated that slow, careful dipping and rack removal would significantly reduce the dragover volume, thereby decreasing the metal concentration in the rinse tanks, especially for irregularly shaped objects like the ones produced in this factory. Considerable dragout recovery was achieved when the racks remained immersed for about 5–10 sec for nickel and when they were allowed to hang in the air above the tank for about 10 sec in the case of chromium plating operations. A comparison of the two methods of dipping is presented graphically in Figure 2.

The soak tanks, electroclean tanks, acid dip tank, and plating tanks do not have outlets for draining and hence every month the contents must be pumped out. There is no surface drain in the plant premises and the plant floor does not slope to facilitate

Figure 2. Results of rinsing experiments conducted during preauditing.



drainage. The water pumped out accumulates along the piping, as shown in the layout diagram, and is drained off to the proposed effluent treatment plant area through open floor-level outlets. The general rinse, nickel rinse, and chromium rinse wastewater is segregated and brought to the proposed effluent treatment area as shown in Figure 1. Three drums collect this wastewater but it was observed that the discharge area was not properly maintained and the drums were blocked and overflowing.

The dragout recovery tanks in use were found to be of very high volume, thus generating more dragout to be recycled. Since the evaporation and dragout rates from the plating tanks were much lower, the volume could not be balanced and solution was lost. The concentrations in the recovery tanks were not ideal for better solution recovery due to the excessive volumes.

RECOMMENDATIONS

Based on the observations made during the preauditing stage and the results of analysis, recommendations were made in three phases: simple, advanced, and future modifications.

PHASE I: SIMPLE OPTIONS

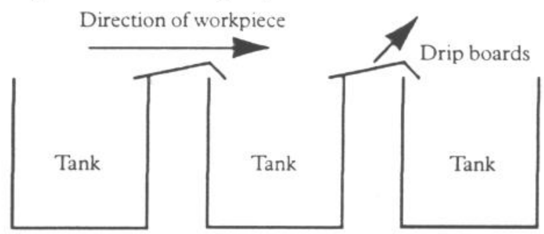
The simple options comprised layout modifications and modifications in time and motion sequences. The layout was modified to optimize the flow of workpieces and control. Since altering the locations of the tanks to decrease the distance between them was not feasible, the installation of drip boards between every two successive tanks was recommended to capture the dragout volume and return it to the previous tank in the sequence. The recommended configuration is shown in Figure 3.

Other general recommendations were as follows:

1) Working platforms of metal planks and bricks were originally used. Proper hard

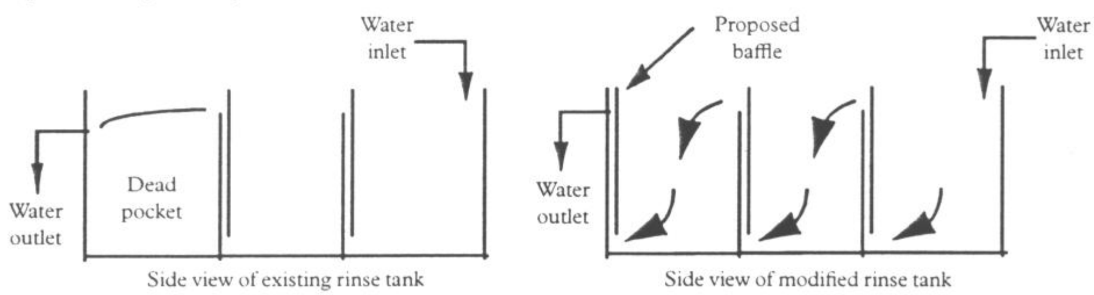
polyvinyl chloride platforms, which are safe to use and easy to handle and move, were recommended to replace the previous platforms.

Figure 3. Installation of drip boards between tanks.



2) The owner was asked to provide the storeroom with shelves to store chemicals and to maintain proper logging of the material inputs and outputs.
3) It was recommended that an intermediate baffle be installed in the final compartment of all the rinse tanks (Figure 4) to induce up-down flow and avoid dead pockets, since the inlet and outlet of the final compartment were at the top. The workers were told not to splash the workpieces in the rinse tanks but slowly move them up and down for more effective rinsing.

Figure 4. Modification of rinse tanks.



4) The filter between the bright nickel bath and the dragout recovery tank was obstructing the movement of the workpieces and resulted in a large amount of spillover. Investigations were carried out to relocate the filter, after which resizing of the nickel dragout recovery tank to accommodate the filter in the middle portion was recommended. This was a perfect solution for the filter problem as well as the oversizing of the dragout recovery tanks.
5) Work distribution and allotment were emphasized to minimize idle time and maximize productivity.
6) The use of control charts was suggested to ascertain plating concentrations on a daily or weekly basis, so that any deviation from normal would be prominent and could be rectified.

PHASE 2: ADVANCED OPTIONS

Advanced recommendations were based on detailed process parameters and process methodologies used in the factory. Proper surface drainage facilities were recommended so that the working area would be clean and safe. It was requested that adequate water measurement equipment be installed at the inlets and outlets to quantify water consumption and wastewater discharge. Tanks that did not have any outlet and piping were to be provided with them so that the need for monthly pumping and the subsequent extra cost could be eliminated.

Air agitation should be provided in all rinse tanks except nickel to avoid oxidation. The rinsing should be continuous as far as possible. The use of deionized (DI) water in the final rinse after chromium rinse tanks was recommended to give a good finish.

A three-stage rinse after the acid dip is not necessary; a two-stage rinse should suffice. The dragout due to the distance between the acid rinse and the two semi-bright nickel tanks should be reduced. Retention time in the acid tank should be about one minute.

An in-house DI water production system was recommended to solve the problem of the high conductivity of tap water. Investigations revealed that buying DI water daily would be uneconomical for the enterprise, and hence installation of an in-house DI water production unit was strongly recommended. Supporting data on the economics of such a system confirm the long-term benefits: capital cost, 225,000 baht; annual operating expenditure, 38,150 baht; net annual savings, 81,850 baht; payback period, 2.7 years; net present value, 277,933 baht; and internal rate of return, 35%.

The rinse requirements and recycling amounts were calculated, and based on the results resizing of the dragout recovery thanks was recommended (Table 2).

Table 2. Summary of rinse water requirements and resizing of tanks.

Rinsing requirement	Quantity
Ni rinse	1.20 m³/d
Cr rinse	2.20 m³/d
Evaporation rates	
Ni plating tanks (semi bright and bright)	192 l/d
Cr plating tanks	40 l/d
Amount to be recycled from dragout recovery tanks (if dragout = 125 l/d)	
Ni dragout recovery tank	317 l/d
Cr dragout recovery tank	165 l/d
Optimum recovery-tank size	
Ni	0.5 m × 1.2 m × 1.1 m
Cr	0.8 m × 0.8 m × 1.1 m

PHASE 3: FUTURE MODIFICATIONS

Future modifications recommended included the design and construction of end-of-pipe treatment based on the flows and concentrations obtained after the modifications suggested for phases 1 and 2 had been made. It was recommended that the proposed second nickel plating line should also be considered and the necessary details of changes in the wastewater flow and characteristics be calculated accordingly.

IMPLEMENTATION STAGE

The time and motion sequence was modified and redeigned for smoother operations and bottlenecks were eliminated. The modified time and motion sequence is presented in Figure 5. The previous three separate tanks for soak cleansing were re-

Figure 5. Modified time and motion study.

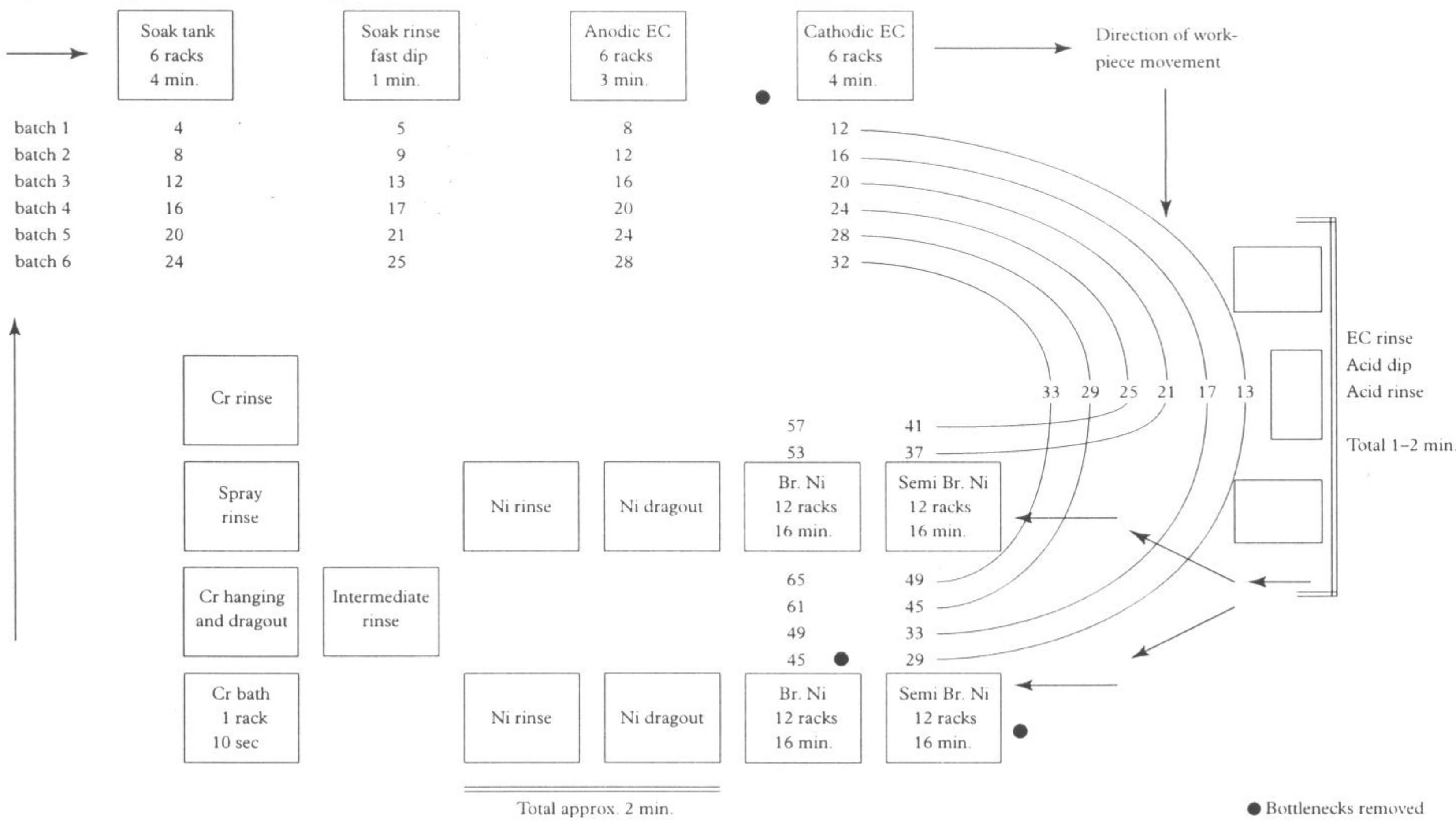
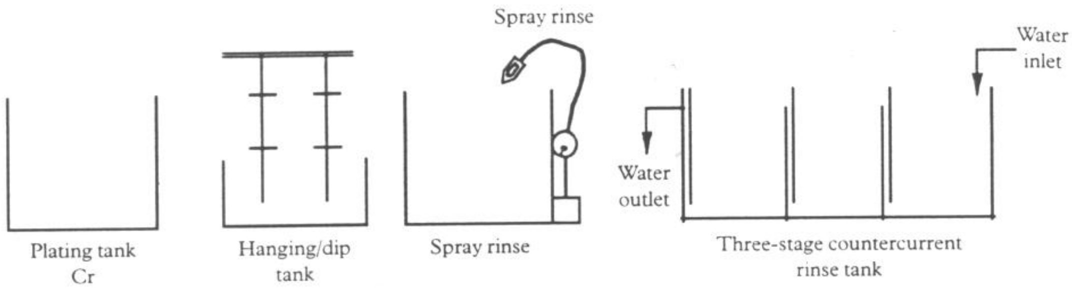


Figure 6. Modified chromium dragout recovery and rinse system.



placed by two tanks, making the configuration simpler. The hazard due to gas burners was eliminated by replacing the gas heating system with an electric one. This modification resulted in annual savings of 32,580 baht.

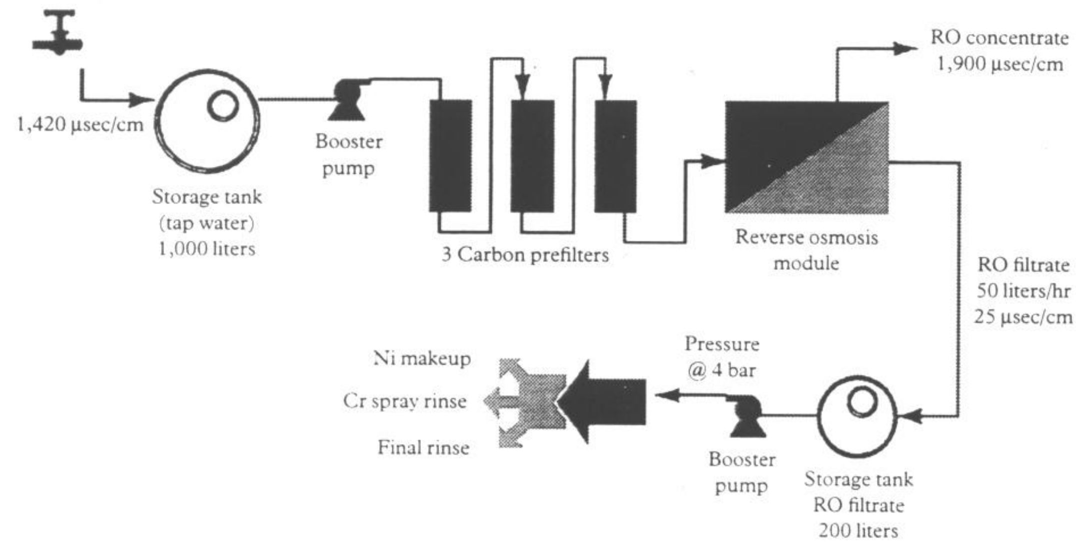
The sequence of the electroclean tanks was modified to the cathodic first and the anodic second to facilitate surface preparation for plating. Due to practical and economic reasons, the two tanks could not be combined into one with a switchover valve. The retention time in the acid dip tank was changed to about 1 minute, as recommended earlier. The first compartment of the acid rinse tank was converted to an empty tank, since the three-stage rinse pattern was not necessary. Moreover, the empty compartment could be used as a holding tank before nickel plating to eliminate any time lags. The filter location was moved to the center of the nickel recovery tank so that dipping can be done on both sides and the dragnet losses are reduced.

Previous discussions and experiments revealed that after dipping in a fairly concentrated solution (but not as high as the plating solution itself), a waiting period, and spray rinsing, the carryover of concentrated solution to the rinse tanks could be reduced drastically and a significant amount of solution could be recycled back into the plating tanks. The modified configuration of the chromium dragout recovery and rinse systems is presented in Figure 6.

Experiments were conducted to determine the effect of spray rinsing on the dragout and the concentration in the rinse tank. Samples were taken and analyzed after every 10 racks for irons, which were slow-dipped in a 116.76-l barrel once without spray rinsing and once after spray rinsing. The results showed that the chromium content without spray rinsing was 25–30 mg/l and that with spray rinsing was 0–12 mg/l. Thus it is evident that spray rinsing reduces a large amount of dragout from the workpiece surface and results in less carryover to the rinse tanks. The installed system discharges a flow of 8 l per minute, but experiments show that 10 racks could be efficiently rinsed in 4–5 l of water. Considering that 12 racks can be rinsed approximately every 15 minutes in an eight-hour work day, the water consumed for spray rinsing per day is 192 l.

As shown in Table 2, the amount that can be recycled to the chromium plating tank is about 165 L. The dragout volume found earlier can be reduced substantially due to the drip boards and the slow-dipping method. Thus it is convenient to transfer the spray rinse water to the hanging tank, where it is heated in order to concen-

Figure 7. Reverse osmosis system for DI water production.



trate it to a volume equal to the reduction in the plating tank. Other general recommendations implemented include the following:

1) Drip boards were installed (as recommended) at all junction points between tanks.
2) Control charts were installed at all major locations like plating tanks, soak and electroclean tanks, etc.
3) The room layout of the buffing section was modified, and the polishing section was separated.
4) All the rinse tanks were provided with a baffle at the outlet end to create the proper up-down flow of water. The settling of solids in the final compartment was reduced due to this modification.
5) Temperature control devices and timer clocks were installed at all strategic locations where immersion time should be controlled.
6) Facilities for a well-equipped laboratory were provided to avoid sending samples to the contracting factory for analysis and to enable spot checks of the concentrations in the plating tanks.
7) Instruments were purchased to measure plating thickness and control the electroplating process.
8) Adequate surface drainage and flow outlets were provided to designated tanks to avoid spillage and other losses during cleaning and emptying operations.
9) The oven-drying method was employed instead of the usual fan or manual airblower drying. This reduces labor and dries the finished products more efficiently, giving a better finish to the workpieces.
10) A reverse osmosis filtration system was installed to produce near-DI quality water. The details of this system are shown in Figure 7. Conductivity measurements showed that the filtrate water produced approached DI quality. For example, tap water has conductivity of 1,420 μsec/cm, the reverse osmosis filtrate 25 μsec/cm, and the reverse osmosis concentrate 1,900 μsec/cm.

OBSERVATIONS IN THE POSTAUDITING STAGE

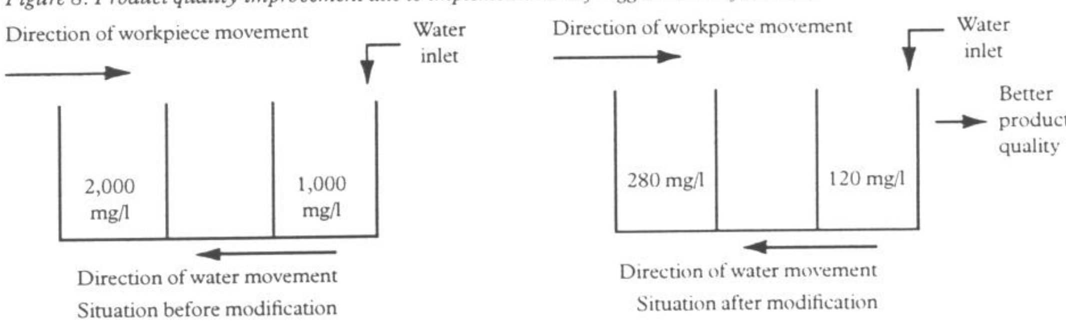
Monitoring similar to preauditing was conducted, and a comparison between the flows, concentrations, and total wastewater load was made. The results obtained are presented in Table 3. The material recovery rate was calculated based on the total

Table 3. Flows and wastewater concentrations before and after modifications were implemented.

	Preaudit			Postaudit		
Sample Location	l/day	mg/l	kg/day	l/day	mg/l	kg/day
Ni rinse wastewater	540	3,495	1.88	1,180	100	0.118
Cr rinse wastewater	820	2,000	1.64	635	280	0.178
Other rinse wastewater combination of (1 + 2 + 3)	450	600	0.27	725	285	0.206
Grand total	1,810	–	–	2,540	–	–

NOTE: Material savings were calulated based on installation of the proposed second nickel plating line, thus assuming that the nickel load would double, i.e., 0.118 × 2 + 0.236 kg/day.

Figure 8. Product quality improvement due to implementation of suggested modifications.



load observed before and after the recommended modifications were made and the results indicated an overall annual savings of 198,600 baht.

Additionally, improvements in product quality were observed due to the lower concentration in the nickel as well as chromium rinse tank in the final compartment of the rinse tanks after modification (spray rinsing). Details on the chromium rinse tank details are presented in Figure 8 as an example. Thus products leaving this compartment are now better rinsed and have an improved surface finish.

CONCLUSIONS

The primary objectives of this study were to achieve pollution prevention and control and reduce material losses by recovering and recycling metal solutions to the extent possible. The suggested recommendations have succeeded in achieving these objectives and thereby reduced the load on the effluent treatment plant considerably (Table 3).

Since material input was not logged and it was difficult to trace the materials in their component form (Bangplee Chromium uses ready-made chemicals of which the composition is not known, and effluent analysis was based on nickel and chromium concentrations and COD only), it was difficult to arrive at a perfect material balance. Since the main objective was to reduce dragout and recycle plating solution along with other waste minimization options, more emphasis was given to this.

Implementation of waste minimization in small-scale enterprises often faces several practical problems due to unorganized and judgment-based process activities. The lack of equipment and process automation also makes it difficult to make substantial changes in the waste generation potential of the enterprises. The conventional audit approach must be modified to suit the requirements and objectives of the individual firm, and recommendations should be made accordingly.

This study successfully demonstrated that the audit approach can adapted to a small-scale enterprise. The net savings achievable due to the modifications suggested in this study of Bangplee Chromium are: savings due to the replacement of gas burners with electric heaters, 32,580 baht; savings due to installation of a membrane filtration system for DI water, 81,850 baht; savings due to material recovers, 198,600 baht; and total annual savings, 313,030 baht (US$1 = 25 baht).