Waste minimization: an effective pollution abatement tool for small & medium scale industries

Dr. C. Visvanathan, Assistant Professor, Environmental Engineering Program, Asian Institute of Technology, Bangkok and **N.T. Lien Ha**, Research Associate, CDG-SEAPO Office, Asian Institute of Technology, Bangkok.

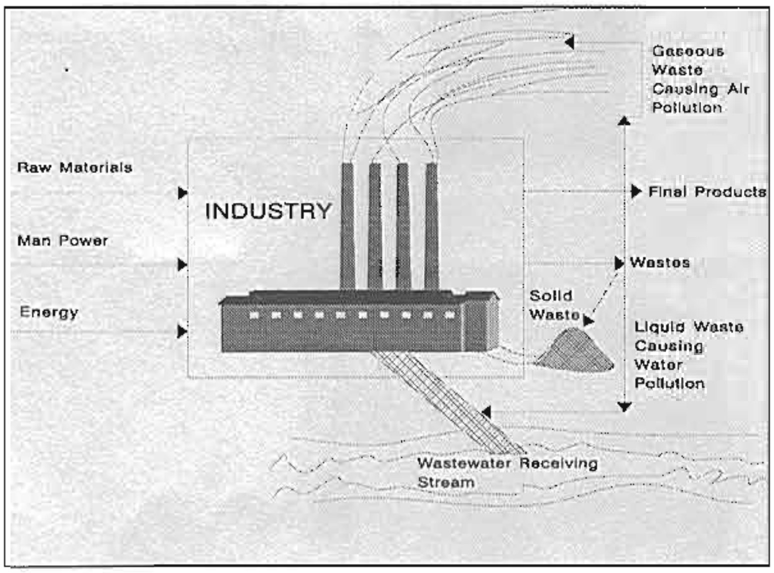
Abstract

Waste minimization is considered to be a "sustainable environmental protection method." It is particularly relevant for small and medium scale industries (SMIs) which not only provide large-scale employment and other economic advantages over larger industries, but also ensure a more equitable distribution of national income. However, SMIs also contribute significantly to overall industrial pollution, but lack preferential access to both capital and new technologies.

This paper examines a small electroplating shop in Bangkok, looking at how waste minimization can create savings from the quantity and strength reduction of wastewater, without any major financial investments. Simple in-plant control measures such as dragout recovery, spray rinsing techniques and rinse water agitation were utilized, enabling the minimization of chemical usage.

An Industry can be defined as a system in which diverse elements called input undergo mechanical, physical, chemical or even biological changes to give rise to desired products and by-products known as output. As part of the production process, polluting waste streams are also generated as schematized in Figure 1. Rapid industrialization for better living standards has led to increased productivity along side with a dramatic augmentation of pollution loads.

Figure 1: Relationship between industry and pollution



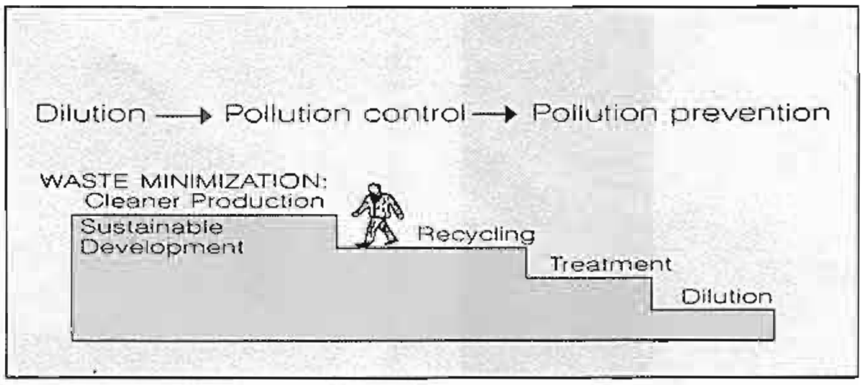
In the early 1960's, when awareness about environmental pollution was just beginning, dilution was considered as the solution to all pollution problems. This practice resulted in the rapid reduction of the assimilative capacity of various natural systems, leading to environmental degradation. Thus, to combat industrial pollution, industries were forced to purify their waste stream prior to discharge. This practice was known as the "end-of-pipe treatment", where no attention was paid to process changes which can lead to waste reductions. This technique has few advantages such as:

straightforward and simple operations, low risk, and meeting the required effluent standards in a short span of time. Lately, industries found that effluent treatment costs increase linearly with increased production, and in many situations "end-of-pipe treatment" provides only a short term solution.

In the "end-of-pipe-treatment" process, waste is eventually transferred from one phase to another. Thus, "phase transfer" is a more appropriate term than "treatment". For example, toxic heavy metals in electroplating effluents are converted by physico-chemical means and are transferred from the aqueous phase to the solid phase. In recent years, the leaching of heavy metals from waste sludge's buried in sanitary landfills caught a lot of attention. Furthermore, more stringent standards were also set for industrial effluents. These require industries to consider the further treatment of sludge, which proportionately increases the cost of pollution abatement.

Figure 2. clearly demonstrates the various phases of environmental protection. Waste minimization/cleaner production are the techniques considered as "sustainable environmental protection methodologies". Here the first three stages are considered to be "reactive", where as the last phase of waste minimization is seen as being "preventive".

Figure 2: Phases of environmental protection



I. What is waste minimization?

Waste minimization consists of source reduction and recycling. Of the two approaches, source reduction is usually preferable to recycling from an environmental perspective [1]. Source reduction is any activity that aims to eliminate the generation of waste/hazardous waste at its point of origin, while recycling is the using, recycling, or reclaiming of materials/waste, including processes that regenerate a material or recover a usable product from it [2]. Waste minimization however, does not include recycling activities which involve disposal and burning for energy recovery [3]. Generally speaking, with waste minimization we are integrating all the environmental constraints into the industrial production units. Waste minimization involves the use of raw materials, processes or operating practices in a manner that prevents the creation of pollutants or wastes at their source, and those practices that reduce the use of hazardous and non-hazardous materials, energy, water or other resources.

Waste minimization can be achieved through a number of practices and approaches as illustrated in Figures 3 and 4.

1 USEPA, 1988
2 UNEP/UNIDO, 1991
3 USEPA, 1992

Figure 3: How to minimise wastes?

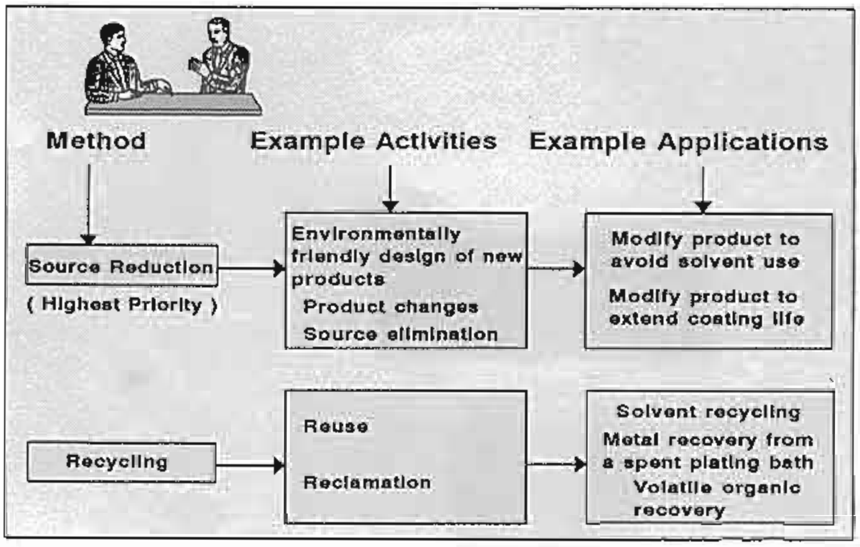
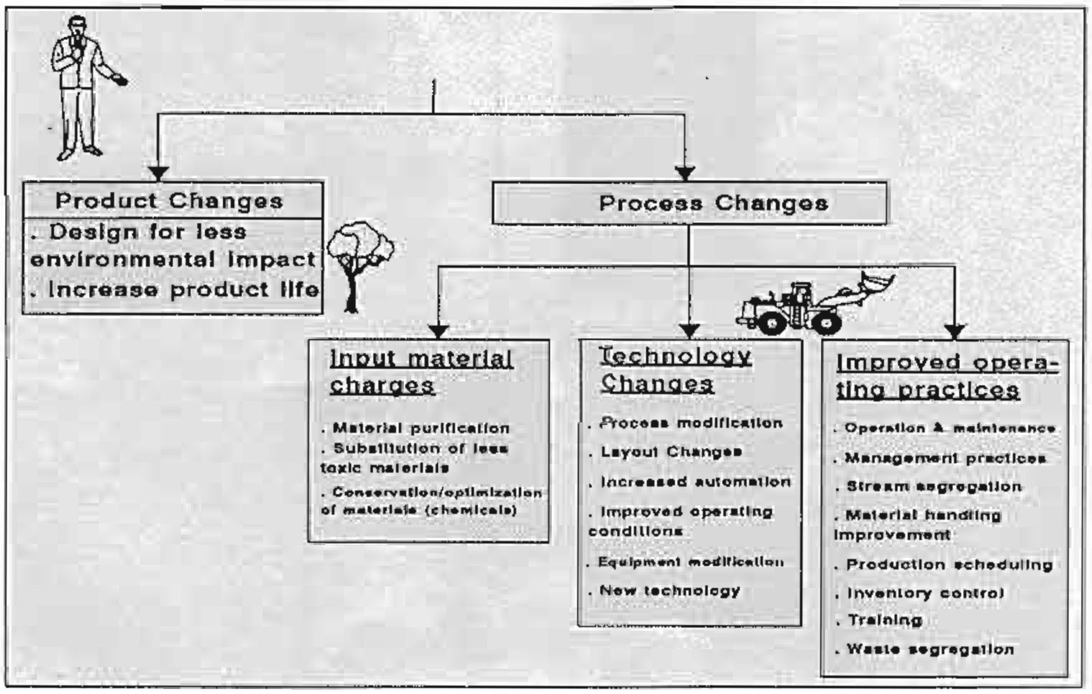


Figure 4: General techniques for source reduction



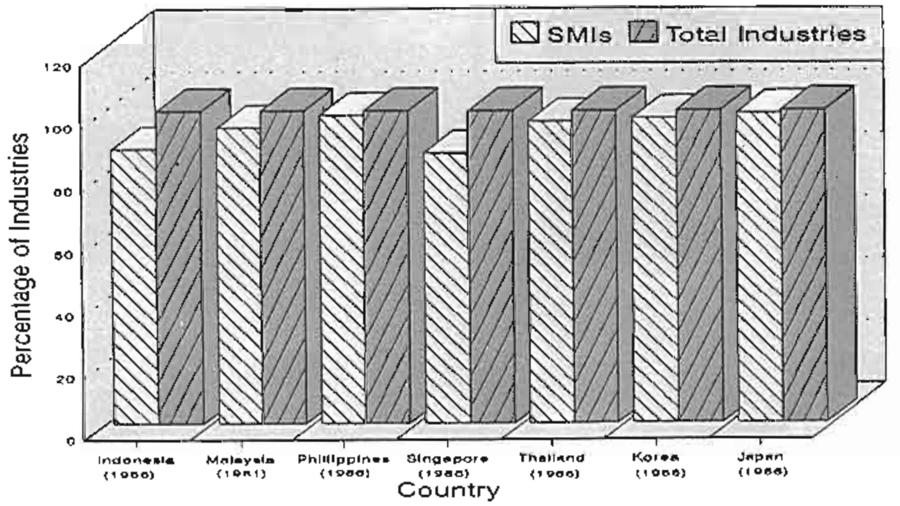
The selection of potential measures which are appropriate for each specific industry to minimize their pollution load depends on many factors, such as the industries size, the waste production in terms of toxicity and/or volume, the significance/benefits of waste minimization options, and the willingness/receptivity of the industry to innovation, etc. For the industry managers to make a sound decision and selection with regard to environmental management, it is essential to conduct a waste reduction audit, which is a systematic, planned procedure with the objective of identifying ways to reduce or eliminate waste. Briefly, a typical audit consists of a thorough account of a plant's operations and waste streams in order to get a deep understanding of material flows in various stages of the production line, and the selection of specific areas to focus on. After the priority areas are established, a number of options with potential for waste reduction are developed and screened. Then environmental, technical and economical evaluations of the selected options are undertaken and finally the most promising options are identified and designed for implementation [4].

II. Small and medium scale industries:

The term small, and medium, scale industries (SMIs) used in this paper is for enterprises with less than 50, and from 50 up to 200 employees, respectively.

SMIs contribute significantly to the strengthening of the industrial structure. Figure 5 shows the percentage contribution of SMIs to all industries in some selected countries in the Asia-Pacific region. This figure indicates that SMIs are a significant and dominant component of the industrial sector of all these countries. This is because they provide immediate large scale employment and have a comparatively higher labor/capital ratio; they need a shorter gestation period and relatively smaller markets to be economical; they need lower investments, offer a method of ensuring a more equitable distribution of national income and facilitate the effective mobilization of capital and skills which might otherwise remain unutilized [5].

Figure 5: SMIs in the Asia-Pacific region



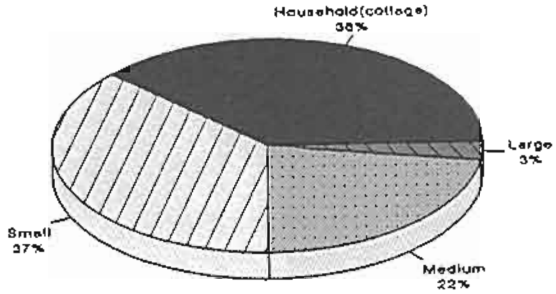
4 UNEP/UNIDO, 1991

5 UN-ESCAP, 1985

Pollution from SMIs:

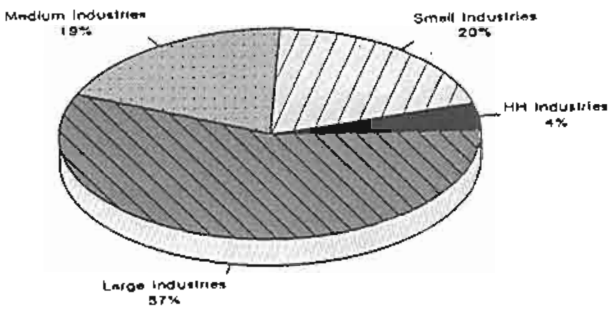
Although SMIs play a vital role in economic development, they also contribute significantly towards overall industrial pollution. For example Samut Prakan, a province of the Bangkok Metropolitan Region (BMR), comprises of 38 percent household industries[6], 60 percent SMIs and 2.6 percent large scale industries [7] (see Figure 6).

Figure 6: Proportion of industries of different sizes in Samut Prakan



As far as the contribution of pollution by industrial size is concerned, Figure 7 shows the BOD load contribution according to industrial size. While 43 percent of BOD load comes from SMIs, and household industries (i.e. 4 percent), the remaining 57 percent is from large scale industries. The BOD load in Samut Prakan province is projected by assuming that the proportion of various industrial categories will remain the same and that there will be no change in production technology or waste treatment by the year 1996 (Fig. 8) It is quite obvious that pollution loads will continuously increase if no precautionary measures are taken.

Figure 7: BOD load according to industrial size: Samut Prakan



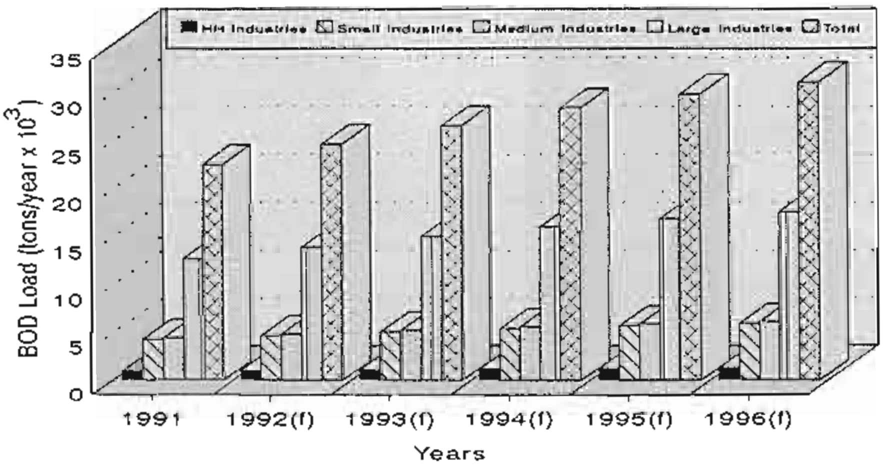
6 household/cottage industries have less than 10 workers

7 TDRI, 1993

Situations similar to that in Samut Prakan may exist in other provinces in Thailand and many other Asian countries. Therefore, it is very important that while planning national pollution control actions, SMIs which contribute significantly to overall national industrial pollution should also be taken into account.

It is true to say that large scale industries produce more pollution than SMIs, as is apparent from Figures 7 and 8. But because of their preferential access to capital investment and to new technologies, it is comparatively easier and more economical for them to control their pollution by utilizing different pollution control techniques. In the case of SMIs a number of factors hinder them from the planning and implementation of pollution control actions. These factors are, a lack of access to resources allowing for investments in pollution control activities, a low level of technology, a lack of space, the non availability of trained personnel at low salaries, etc. The question which subsequently arises is that when SMIs face problems in controlling their pollution what steps should be taken against them in order to prevent further environmental degradation? In the long run, considering the pollution cost to the product cost, can SMIs compete with large scale industries? One needs to ask whether SMIs should be closed down, or whether strong administrative actions should be taken against them so as to reduce their pollution levels. In reality however, these are not the solutions to the problem. The solutions lie elsewhere. These need to be addressed and implemented to insure the pollution free survival of SMIs.

Figure 8: Projection of BOD load in Samut Prakan



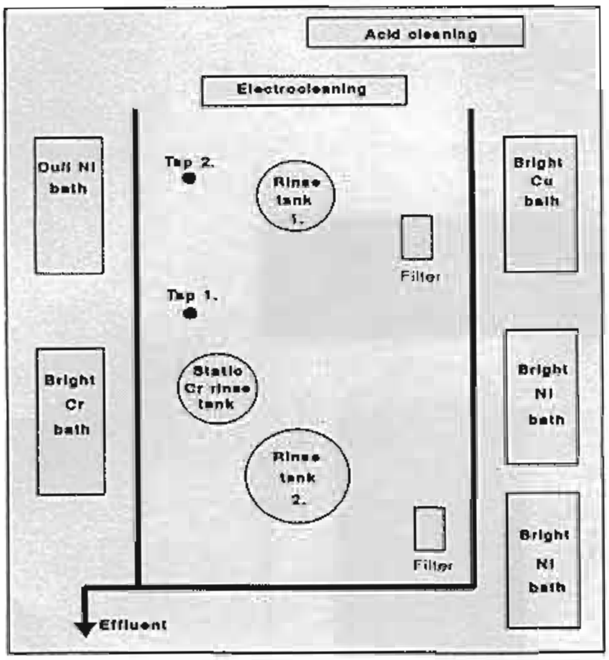
Pollution control problems faced by SMIs:

There are several problems faced by SMIs in controlling their pollution. These problems are mostly technical, economical, educational, etc. and need to be given adequate consideration.

The problems that prevent the effective abatement of environmental pollution from SMIs are more economical, rather than technical in nature. Nevertheless, these two factors (economical and technical) are closely inter-linked, since the common goal is to develop technical solutions to environmental pollution problems. In the case of SMIs, the technical and economical aspects of pollution control assume somewhat distinctive dimensions:

1. SMIs are generally located in highly urban centers and in already congested capital cities. The availability of infrastructure facilities, proximity to a large market, and easier access to financial sources are the primary reasons for this.

Figure 9: Layout of the electroplating shop



During the process the work pieces are washed directly under the tap. There are two rinse tanks used for the whole operation system. Tank No.1 is used for rinsing after the dull Ni and bright Cu plating process and tank No.2 is used for rinsing work pieces after the Ni plating process. Therefore the wastewater contains mainly three components: Cr^{6+} in the form of $Cr_2O_7{}^{2-}$, Ni^{2+} and Cu^{2+}, as shown in Table 1. The analysis of wastewater from the shop showed a wide fluctuation in quantity and quality. The wastewater samples were collected in separate plastic buckets. However, during the actual process operation, the tap is kept open continuously. Thus more diluted wastewater can be expected than in the analyzed data. In general, the whole process consumes about 3-5 m^3 per day of water. At present, wastewater from this plant is simply discharged directly to the nearby sewer system without any treatment.

Table 1: Composition of wastewater

Concentration	Minimum	Maximum	Quantity m^3/day
Cu^{2+} mg/L	74	1100	0.2 - 1.3
Cr^{6+} mg/L	50	2340	0.9 - 3
Ni^{2+} mg/L	10	2482	

3.1. Experimental investigation

Implementation of in-plant control measures

The initial in-plant control waste auditing revealed that this plant generates essentially 4 kinds of wastewater, which originate from: a) Cr plating, b) Ni plating, c) Cu plating, and d) electroplating (alkaline) and acid cleaning. The major focus of the work was on control and treatment of the first three metal bearing waste streams. The last waste stream which mainly contained suspended solids, acid and alkali, contributed 40 percent of total wastewater generated at this plant. Therefore, considering its non-hazardous nature and high volume it seems to be more appropriate that this last stream be discharged directly into the sewer after neutralization.

The layout of the electroplating shop with process modifications is presented in Figure 10. The major orientation of this modification can be summarized as follows:

Spray rinsing techniques - an easy method to increase profits

i) **Wastewater segregation:** Chromium, nickel and copper bearing wastewater was segregated and collected separately. These waste waters were then treated and concentrated solutions (Cr, Ni, Cu) were recovered for reuse or recycling. Four more buckets installed in series at both taps 1 and 2 served the following purposes:

(a) Segregation of different metal bearing wastewater.
(b) Reduction of rinse water consumption.
(c) Recovery of drag-out solution

ii) **Control of positioning and withdrawal of workpieces:** The workers were asked to orient parts so that only a small surface area came into contact with liquid surfaces as it leaves the plating solution, as well as to hold the workpiece for sometime above the plating bath after emerging from the bath in order to reduce the volume of drag-out.

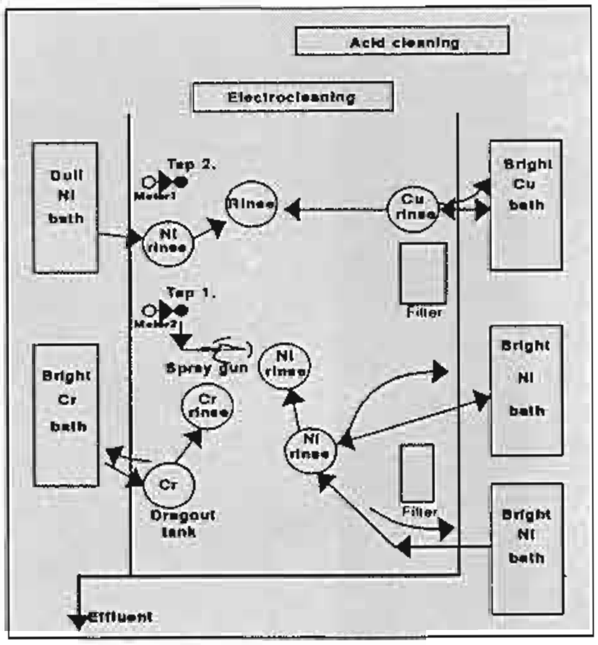
iii) **Simple drag-out recovery:** This was implemented by using a plastic bucket to capture drips from the plating solution as the workpieces were taken out of the tank before rinsing. This bucket was used as a drag-out tank at the same time as which the workpieces were sprayed with a small amount of water before being rinsed. The solution was then returned to replenish the plating bath.

iv) **Rinsing effectiveness**: This was improved by using a spray rinsing technique (a spray gun was installed at tap 1.). A jet rinse with a high velocity and a small amount of water was used, and spray effluent was trapped by the drag-out bucket so as to recover the drag-out.

Fresh water was introduced at the bottom of rinse tanks by nozzles to provide agitation during rinsing so as to improve the effectiveness of rinsing .

v) **Monitoring water consumption** : Water-meters were installed at both tap 1 and tap 2 for monitoring the water consumption.

Figure 10: Electroplating shop with process modification



3.2. Results of the implementation of in-plant control measures

i) Water consumption

Records of water consumption before and after the implementation of process modifications are presented graphically in Figures 11 and 12.

Fig.11: Water consumption at tap 1.

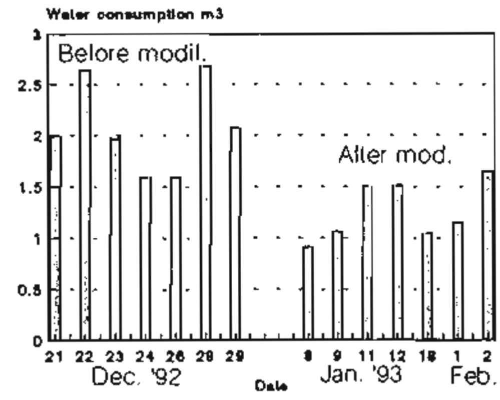
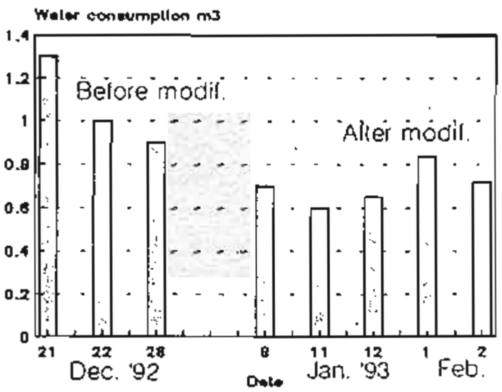


Fig.12: Water consumed for rinsing at tap 2.



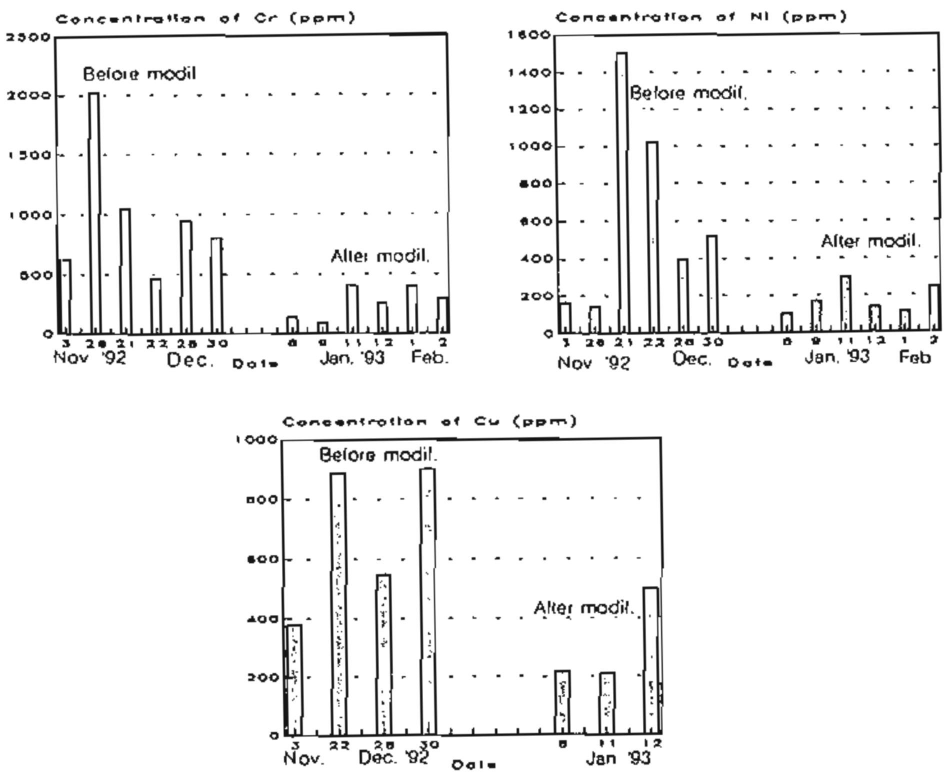
From Figures 11 and 12, it can be seen that after the implementation of process modifications, the water consumption recorded at tap 1, and for rinsing purposes at tap 2, decreased considerably - by 39.4 percent at tap 1 and 34.6 percent at tap 2. Total water consumption shows an average reduction of 18.7 percent.

However, it was found that there was no significant reduction in total water consumed at tap 2. This could be explained by the fact that the major portion of water from tap 2 was used for washing and cleaning the work pieces. It was found that water used for cleaning purposes represented approximately 78.5 percent of total water consumption at tap 2, and about 40 percent of the water used for the whole process at both taps. As stated earlier, the wastewater produced by this cleaning process contains mainly suspended solids and has alkaline characteristics. In this study it can be considered as a non-polluting stream because it does not contain any heavy metal or toxic substances. After neutralization it can be discharged directly in to the common sewer.

ii) Concentration of heavy metals in wastewater

The variation of concentration of heavy metals in wastewater generated before and after process modification is illustrated in Figures 13, 14 and 15.

Figures 13, 14 & 15: Heavy metal concentrations



From Figure 13 it can be seen that the chromium concentration in the wastewater generated has decreased significantly after process modifications. There was about a 73 percent reduction in the average Cr concentration observed in the wastewater generated.

Also Figure 14 and 15 indicates the decrease in Ni concentration in wastewater after process modification. The average reduction in concentration was estimated to be about 71.3 percent for Ni and 54.6 percent for Cu.

From the results obtained after implementing the proposed process modifications it can be seen that it was not feasible to achieve a zero discharge of heavy metals from electroplating operations. However, substantial reductions were possible in both the volume and the metal concentration of wastewater. In addition, it was noted that rinsing water bearing heavy metals and wastewater produced from the cleaning process before plating should be strictly segregated, since the cleaning water does not contain any heavy metal, but only suspended solids, and it represented about 40 percent of the total plating process water. This could significantly reduce the cost of treatment of waste streams bearing toxic metals.

iii) Cost evaluation

Estimations of the savings due to the reduction of water, wastewater and chemical usage were based on the comparison between the costs of end-of-pipe treatment under present conditions with those associated with the process modification results.

Savings due to wastewater reduction

Average water consumption: $4.17\ m^3/day * 20\ day = 83.4\ m^3/month$ (20 working day/month)
$= 83.4\ m^3 * 1.3\ ton/m^3 = 108.4\ ton/month$

Water reduction: $18.7\% * 83.4\ m^3 = 15.6\ m^3$

The total cost saving due to water and wastewater reduction is:

(140.4 + 3174.4 + 906 + 7594 + 302) Baht = 12,117 Baht per month

The estimation of savings due to the amount as well as the strength of wastewater is presented in Tables 2 and 3.

Table 2: Saving due to wastewater reduction

	Quantity reduced	Cost/unit (Baht)	Savings (1 month) (Baht)
Water reduction	$15.6\ m^3$	$9\ B/m^3$	140.4
Reduction of wastewater requiring treatment	$15.4\ m^3$ = 20.2 ton	**157B/ton	3171.4

(**: Cost of treatment at the central treatment plant, Samae Dam. These prices are to be revised in the near future)

Table 3: Savings due to metal concentration reduction

Reduction by pour-back of dragout solution	Reduction of concentration in wastewater (**)	Reduction in wastewater generated m^3	Amount of material saved	Equivalent to	Cost/unit (*)	Savings (1 month) Baht
Cr^{6+} reduction	720/5 mg/l of Cr^{6+}	22% * 15.6 = 3.43	495.8 g Cr^{6+}	476.7 g of CrO_3	950 B/kg of CrO_3	906
Ni^{2+} reduction	445.8/5 mg/l of Ni^{2+}	34% * 15.6 = 5.3	472.6 g Ni^{2+}	2260 g of $NiSO_4.7H_2O$	3360 B/kg of $NiSO_4.7H_2O$	7594
Cu^{2+} reduction	370.9/5 mg/l of Cu^{2+}	12% * 15.6 = 1.87	139.4 g Cu^{2+}	547.8 g of $CuSO_4.5H_2O$	550 B/kg of $CuSO_4.5H_2O$	302

(**) = divided by a dilution factor of 5. (The dilution factor was introduced to compensate for continuous dilution of the actual waste stream due to open taps used for rinsing and cleaning)
(*) = Cost based on the pure chemicals of laboratory grade.

Conclusions

This case study was developed with the objective of setting up a demonstration project: "revealing the profitability of clean technology in small scale electroplating unit". The research was conducted in a small-scale electroplating shop, located in Bangkok. A set of simple in-plant control measures such as drag-out recovery, spray rinsing techniques and rinse water agitation were implemented. Quantitative data, obtained from the monitoring of wastewater before and after process modifications, have revealed that it was not possible to achieve a zero discharge of heavy metals from electroplating operations, however substantial reductions were made possible both in quantity and strength of wastewater generated. Water consumption was reduced by approximately 35 percent of total rinsing water, which is 19 percent of total process water consumption. Average metal concentrations in wastewater was reduced by 73 percent for Cr-, 71 percent for Ni- and 54 percent for Cu-plating rinse water.

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