A NEW GENERATION OF POLLUTION PREVENTION TECHNOLOGY AND ITS APPLICATIONS IN ELECTROPLATING PLANTS

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Pollution Prevention (P2) has been one of the national goals in environmental protection over the past decade. An implementation of P2 is always associated with a significant capital investment. This hinders their wide applications in the electroplating industry. This paper is to explore an opportunity of developing a new generation of P2 technologies, namely Profitable P2 (or simply P3) technologies that can also make profits for plants. The P3 concept can be justified through a deep analysis of process operation and waste generation mechanism. It will show that the development of P3 technologies will be a new direction of R&D for environmental protection. An application of a P3 technology in a zinc cleaning system is briefly described to show the attractiveness for the industry.

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Introduction

As a major pollutant generator in the manufacturing industries, the electroplating industry pays hundreds of millions of dollars per year for waste treatment and disposal.[1] As environmental regulations become increasingly stringent, how to effectively reduce waste in the first place has greatly challenged the industry.

According to EPA, pollution prevention (P2) means the maximum feasible reduction of all wastes (wastewater, solid waste, and air emissions) generated at production sites.[1] Over the past decade, numerous P2 technologies have been developed for the electroplating industry. One group of technologies is basic and is for source reduction, recycling/reuse, and pretreatment. Their implementation is usually easy and simple. Nevertheless, the P2 effectiveness is always limited.[2] In recent years, another group of P2 technologies are being developed that focus on technology change, use of alternative metals, and in-plant recovery/reuse and treatment. This group of technologies is much more effective in waste reduction.[3] However, a significant capital investment is always required in implementation. Another concern of using this group of technologies is the uncertainty of maintaining plating quality and production competitiveness, and the need of significant change of the process. Hence, their applicability to and acceptance by the industry are yet to be proven.

Note that the majority of over 8,000 electroplating job shops and captive shops in the nation are medium or small in size. They usually lack P2 expertise and have no adequate funds to invest P2 projects. Platers urgently need the least expensive P2 technologies for maximum waste reduction, while their economical competitiveness can be maintained.[2]

In this paper, a novel concept, named profitable pollution prevention (or P3 for short), is introduced. This concept extends the conventional P2 concept significantly by adding a new dimension, i.e., economics, to it.

From P2 To P3

A safe P2 effort that most plants prefer is the installation of wastewater pretreatment facilities (WTF), if it is affordable. Figure 1 shows a general structure of an electroplating plant that consists of electroplating lines and WTF. Chemicals, energy, and water are consumed in cleaning, rinsing, and plating operations in the plating lines. The waste water is treated. In the plant, waste is generated from the tanks in the plating lines (end-of-process waste) and WTF (end-of-plant waste). Obviously, the reduction of the end-of-process waste is the focus for the most effective P2.

The merit of P3 is the simultaneous realization of waste reduction (environmental

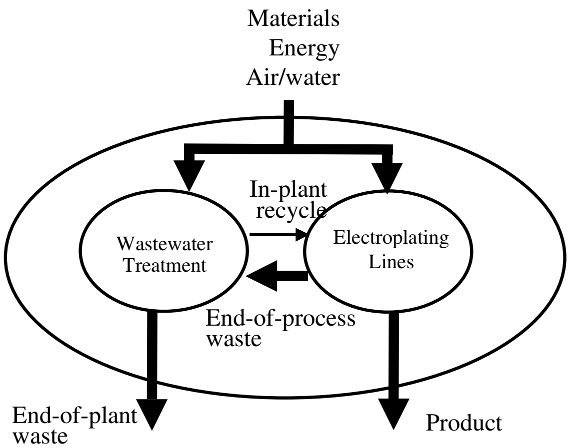


Figure 1. Conventional P2 approach in an electroplating plant.

impact) and improvement of production (economical incentive). This can be expressed as,

$$P3 = \text{Waste}\downarrow + \text{Production}\uparrow \quad (1)$$

$$\text{Waste}\downarrow = \text{Dirt removed}\downarrow + \text{Chemicals}\downarrow + \text{Water}\downarrow + \text{Energy}\downarrow \quad (2)$$

$$\text{Production}\uparrow = \text{Product quality}\uparrow + \text{Production rate}\uparrow + \text{Operating cost}\downarrow + \text{Capital cost}\downarrow \quad (3)$$

It is clear that the reduction of chemicals, water, and energy consumed in a production line in equation (2) must lead to the direct reduction of operating cost and indirect reduction of capital cost in equation (3). The key of waste reduction is the control of production quality. The reduction of dirt removal from parts can directly contribute to waste minimization, and the reduction of chemicals, water, and energy in equation (2) and thus the operating cost in equation (3). Moreover, it will shorten the processing time in cleaning tanks and thus improve the production rate in equation (3). A critical concern is again the cleaning and rinsing quality as included in equation (3). This analysis has shown that the deep understanding of the process is the key for ensuring both environmental and economical benefits.

The fundamental component of P3 is the process principles that explain how parts are cleaned, rinsed, and plated, and how waste is generated in various operations. These principles are nothing but mass and energy balances, thermodynamics, and kinetics. They can be used to study process steady-state and dynamic behavior and to develop P3 strategies.

The end-of-process waste can be divided into two groups, unavoidable and avoidable. The unavoidable waste is generated by the removal of the minimum amount of dirt from the surface of parts, according to the cleaning quality. The main portion of the waste is stationary that is remained in cleaning tanks. The rest is mobile that can enter succeeding tanks and finally enter wastewater. Through drag-in/drag-out, certain amount of chemical and plating solutions are also carried over to rinsing systems and finally enter wastewater. This should be avoided to the maximum extent. Another type of avoidable waste is related to parts cleaning, rinsing, and plating. In reality, the completely dirt-free cleanness is not necessary for parts before plating. In production, many barrels of parts are overly cleaned, while many others are not clean enough for quality plating. Obviously, we should avoid overly cleaned situation, then the consumption of chemicals and water, and the processing time in relevant tanks can all be reduced. The focal point of the operational strategy is the identification of the upper limit and the way of controlling the process operation.

Figure 2 shows that when P3 technologies are applied to the plating line, the chemicals, energy, and air/water consumed in the process and WTF will be reduced, the end-of-process waste will be reduced, the waste load of the WTF will be reduced, thus the end-of-plant waste from the

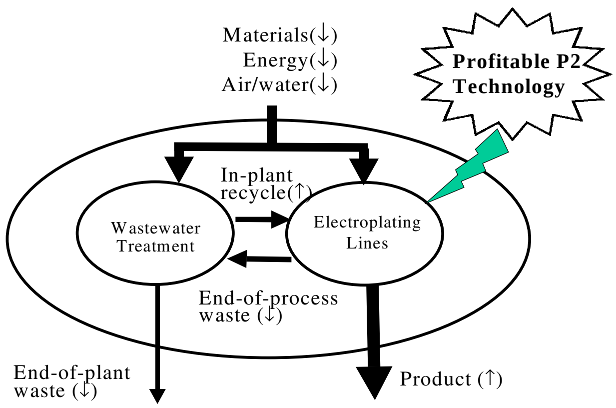


Figure 2. P3 approach in an electroplating plant.

WTF will be reduced, and the production will be improved.

P3 Technology Development

The development of P3 technologies must be for clean and cost-effective process design as well as for clean and optimal process operation. To be effective, P3 technologies must consist of at least four types of strategies as follows.

- Strategy for reducing waste generated in each processing unit.
- Strategy for reducing waste transferring among units.
- Strategy for reducing chemicals, water, and energy.
- Strategy for ensuring cleaning, rinsing and plating quality.

The four types of P3 strategies are closely related. The central point is the understanding of a plating process. This understanding can be obtained through developing plant models. The models should be fundamental that can reveal precisely the cause-effect relationships among the quality, productivity, waste reduction, and costs. The models should be dynamic so that the process behavior, such as parts processing status, solvent solution cleaning capability, rinsing water contamination level, and plating solution capability at any time can be characterized. Moreover, the models should be plant-wide so that the P3 decisions can be made at the system level, rather than at a specific unit level.

Over the past five years, Huang and his students have developed a variety of unit-based process models.[4-9] These include the models for all types of cleaning, single and concurrent rinsing, and basic plating operations. The pioneering modeling work has been proven very valuable for the development of comprehensive P3 technologies. We enhance the previous modeling to the plant-wide integrated modeling and model-based optimization.

The P3-oriented optimization is twofold, waste minimization and optimal production. As stated before, these two objectives are consistent. This minimization must follow process operational constraints in order to meet cleaning, rinsing, and plating requirement.

P3 Application

The application of a P3 technology, Optimal Solvent Reduction in a Cleaning System, is briefly described here.

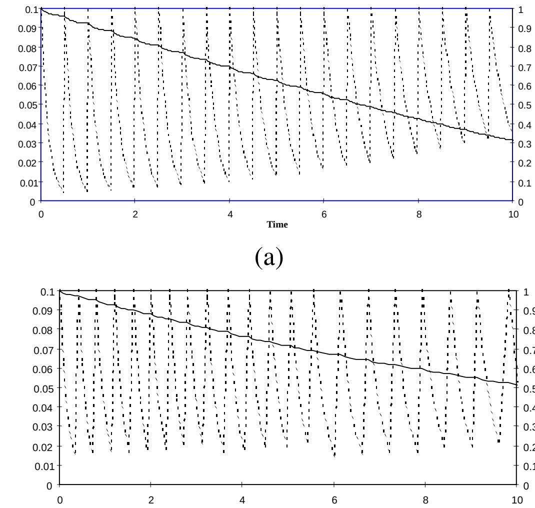
In a soak cleaning tank, the original solvent concentration is 10%. Each barrel of parts is scheduled to have four minutes of processing in the tank. The chemicals are added in about every 20 barrels of cleaning interval. It is required that the dirt residue on parts surface should be no more than 20%. It has been found that the last several barrels of parts in every 20 barrel cycle are not clean enough in operation. The plant is seeking an opportunity of improving cleaning quality without increasing chemical consumption, and without changing the chemical addition pattern.

Using the cleaning model developed in the preceding section, computer simulation has been performed. Figure 3(a) depicts the dynamic responses of the parts cleaning and chemical consumption in the tank, using the original operational procedure. The dotted curves represent the dirt removal of those barrels consecutively. It shows that the first barrel has only 4% of dirt remained after cleaning, while the 20th barrel has the dirt residue of 37%. At the end of the cycle, the chemical concentration in the tank is only 3.2%. The simulation shows that the last five barrels are all not clean enough (> 20% of dirt residue). The original procedure is simple, but is proven not acceptable.

This process can be optimized to improve cleaning efficiency and to reduce chemical consumption, while the production rate is kept nearly the same (20.5 barrels after optimization, slightly more productive). As shown in Figure 3(b), the dirt residue of the part surface of each barrel can be controlled to 20% or slightly lower; there is no barrel overly cleaned or unqualified. After a cycle of 20.5 barrels of cleaning, the chemical concentration in the tank is 5.2%. The chemical consumption per barrel cleaning is reduced from 0.328 to 0.26 unit on average. This implies 20.8% of savings of chemical, or the reduction of waste by nearly the same percentage. The only inconvenience in operation using this improved operational strategy is uneven processing time of each barrel. Apparently, this inconvenience will no longer exist if the process is automatically controlled.

Concluding Remarks

Effective P2 technologies always require significant capital investment. This has hindered their wide applications. On the other hand, a large number of P2 technologies focus on the reduction of end-of-plant waste, rather than end-of-line waste. This is really a passive way for P2. In this paper, we introduce a new concept, profitable P2, i.e., P3. This concept not only inherits the merit of traditional P2, but also adds the economical incentives. The main focus of P3 is on the process that generates waste. Thus, the minimization of end-of-process waste is the target. The application of a P3 technologies has demonstrated the attractiveness and opportunity for the industry to simultaneously realize P2 and optimal production. It is believed that fully development of P3 technologies will soon become a new direction in environmental protection in this decade.



(a) (b)

Key: Chemical concentration;
- - - - - - Degree of dirtiness of parts

Figure 3. Simulation of a cleaning tank: *(a)* Process dynamics of the original operation, (b) Process dynamics of the optimal operation.

Acknowledgment

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