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# Optimization of wastewater electrolysis using life cycle assessment and simulated annealing

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Abstract: LCA (Life Cycle Assessment), that unifies the scale of various environmental impacts, and simulated annealing are applied to optimizing electrolysis of wastewater from PCB (Printed Circuit Board) production. The changes of environmental impact can be quantified with LCA and the total changes of environmental impacts can be expressed as a function of power consumed, Cu recycled, $Cl_2$, NOx and SOx discharged through restriction of feasible reactions. In a single-variate condition, the environmental optimum can be easily obtained through plotting and comparing each environmental impact value. In 8V potentiostatic electrolysis, the lowest environmental impact can be achieved after 90min. To optimize a multi-variate conditional system, simulated annealing can be applied and this can give the quick and near optimum in complex systems, where many input and output materials are involved, through experimentally measured values without a theoretical modeling

## 1. Introduction

PCB (Printed Circuit Board) is made of bakelite or epoxy resin plated with copper. The plated copper is removed according to circuit board design. The function of PCB is to transfer electric signals in the electronic and electric products. To produce PCB, many sub-processes such as Desmear process, Micro-etching process, Chem-Plating process, Plating process and Rinsing process, are needed. Also, various input material such as epoxy resin, copper, chemical compounds, electricity, and industrial water are needed in each sub-process. Wastewater from PCB production process contains the various materials that are used in each sub-process. Among the various materials in wastewater, copper can be removed by electrolysis and removed copper can be reused in PCB production process. Cu recycle will reduce the total amount of raw input materials to produce a unit of PCB and the reduction of total amount of raw input material will reduce the production cost for PCB. Also, reduction of raw input materials means reduction of environmental impacts from raw material extraction and Cu removal from wastewater will reduce aquatic toxicity. However, emission of toxic gas that emitted through wastewater electrolysis may enlarge the environmental impact. Therefore, searching for the optimal point that has the minimal environmental impacts are needed to operate electrolysis equipment. The purpose of this study is to demonstrate how the environmental impacts of wastewater electrolysis can be minimized with LCA (Life Cycle Assessment) and Simulated Annealing. During electrolysis the transformation of chemical compounds in wastewater can be measured and the changes of environmental impacts can be quantified with LCA. Finally, the changes of environmental impact, which is dependent on electricity consumed and electrolysis time in the potentiostatic condition, can be optimized with Simulated Annealing.

## 2. Data acquisition and process

Three main technologies were fused to optimize wastewater treatment process in this research. Firstly, electrolysis was used to remove and recycle copper in wastewater. Secondly, LCA was used to quantify the environmental impact that was released in electrolysis. Finally, simulated annealing was used to search the environmentally optimal condition in electrolysis (Fig.1).

### Wastewater electrolysis condition

To acquire raw data for optimization, electrolysis of solution, that has similar composition of wastewater from PCB production process, was executed. The solution contains $Cu^{2+}$, $Cl^-$, $NO_3^-$, and $SO_4^{2-}$ and the concentrations are 2700ppm, 76.3ppm, 64.2ppm, and 682ppm, respectively. The electrolysis condition was potentiostatic 5V to 12V with interval of 0.5V during 2 hours and the solution was sampled every 5 minutes throughout electrolysis. Consumed electricity is measured by galvanometer. Cu in solution was measured by AAS (Atomic Absorption

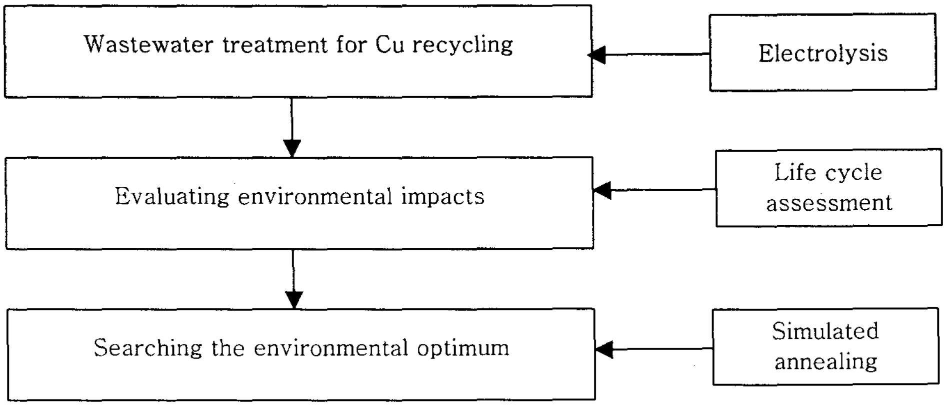


Fig. 1. Fusion of three technologies in this study.

Spectrometer) and $Cl^-$, $NO_3^-$, and $SO_4^{2-}$ were measured by IC (Ion Chromatography). To evaluate environmental impacts with LCA, feasible chemical reactions were limited as $Cu^{2+}$, and $H^+$ reduction on cathode and $SO_4^{2-}$, $NO_3^-$, $Cl^-$, and $O^{2-}$ oxidation on anode (Chiang, 1997). The amounts of emitting gas of SOx, NOx and $Cl_2$, can be calculated by measuring the losses of $SO_4^{2-}$, $NO_3^-$, $Cl^-$ in solution. The $O_2$ and $H_2$ gas were not considered in LCA because they do not have any environmental impacts (Fig.2).

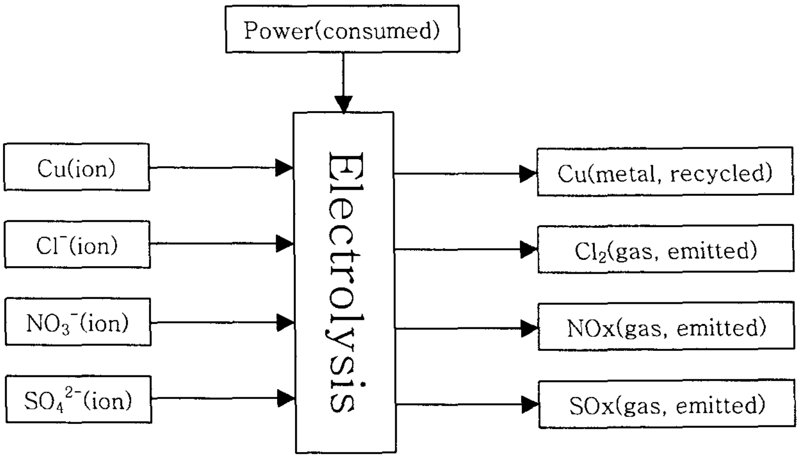


Fig. 2. Flows of materials during the electrolysis.

**Evaluating environmental impact of wastewater electrolysis with LCA**

In this study, acidification, aquatic ecotoxicity, eutrification, global warming, human toxicity, ozone depletion, photochemical oxidation and terrestrial ecotoxicity (LCANET, 1996) was used as categories to evaluate the environmental impacts. Aquatic ecotoxicity category can be separated to ground water and seawater (Schulze, 2001), but it was not applied in this study because of limitation of database and detecting devices. All database used in this study for characterization, normalization and weighting factors is based on the research of Huijbregts (2000) and database of Gabi 3.0. Normalization and assignment of weighting factor in LCA can unify the scale of various environmental impacts and the environmental impacts that have the unified scale can be expressed in the object function for optimization. In potentiostatic 8V condition, the environmental impacts have the minimum value at 90min (Fig. 3). The total environmental impacts are increasing after 90min as the rate of Cu removal decreases and the rate of SOx emitting increases.

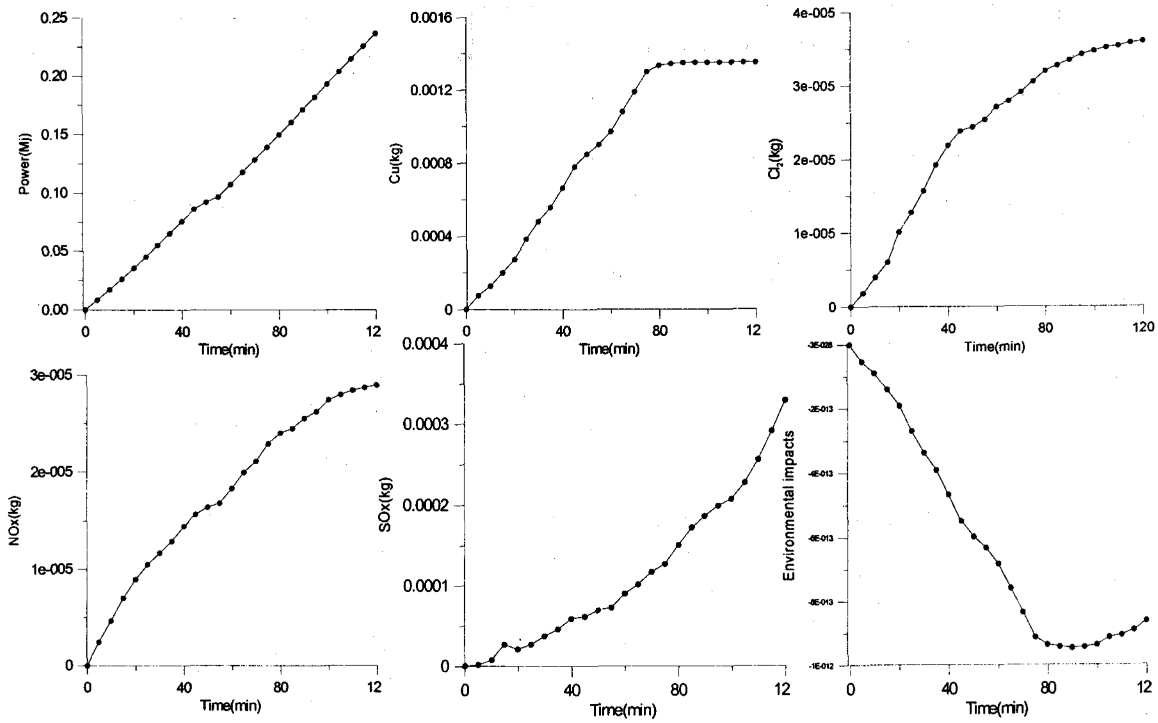


Fig. 3. Changes of environmental impacts during 8V potentiostatic electrolysis.

**Environmental optimization with simulated annealing**

Simulated annealing was used to search the optimum point that has the minimal environmental impacts in various potentiostatic conditions. 43% of the solution through simulated annealing are within the range of 0.5V and 5min from the global minimum (8.5V, 80min) and 85% of the solution through simulated annealing are within the range of 1V and 10min from the global minimum (Fig. 4). Thus, simulated annealing can be applied to search the quick and approximate optimal point of environmental impact.

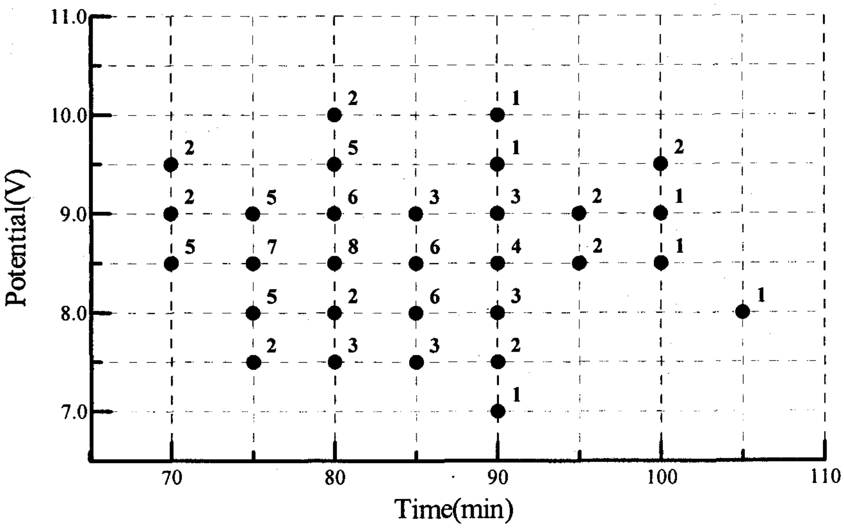


Fig. 4. The frequency of simulated annealing solutions.

## 3. Results and discussion

To find the optimal wastewater electrolysis condition, LCA as the tool for assessing environmental impact and simulated annealing as the algorithm for searching the optimum are applied. LCA can make object function for environmental optimization because it unifies the units of various environmental impacts through characterization, normalization and weighting factors. Simulated annealing can search the optimal condition, where the environmental impact goes to the minimum value, quickly and accurately.

It needs to restrain the compositions of wastewater and chemical reactions in electrolysis, because every component in wastewater and reaction in electrolysis cannot be identified. However, it is possible to make proper modification, if the focusing materials and the scales of researches are changed. LCA can be applied efficiently to in-field operation of environmental equipments, because the environmental impact can be estimated directly through monitoring the concentration of each material in wastewater.

To use simulated annealing for searching the optimal condition, control parameter, loop length, perturbing method should be set up initially. Proper values that can move the solution to the optimal value quickly and accurately were selected through trial and error correction after a few times of pre-simulation. Consideration about antithetic requirements; time and accuracy should be judged before the setting of each parameter, because it affects the elapsed time of algorithm and the accuracy of solution seriously. Because all that is used for the environmental optimization with simulated annealing is data measured from experiments, this method can be applied to complex process effectively. Also, when a large amount of data is accumulated from in-field operation, simulated annealing can be more effective tool than when it deals with a small amount of data. In advance, LCA and simulated annealing with thermodynamic and electrochemical modeling can be used to simulate the environmental impact when designing and adjusting new environmental treatment equipment.

## 4. Conclusions

Applying LCA and simulated annealing to wastewater electrolysis optimization from PCB production process, following conclusions can be achieved;

1) Using the characteristic of LCA, which unifies the scale of various environmental impacts, object function for environmental optimization can be acquired and simulated annealing can be easily applied as optimization algorithm.

2) The function used for environmental optimization should be adjusted when the different characterization, normalization, weighting factor were used or the different restriction of feasible reactions was used.

3) In 8V potentiostatic electrolysis, 90 min has the lowest environmental impact. The electrolysis for wastewater treatment should be stopped in 90 min because the rate of Cu recycling decreases and the rate of toxic gas emission increases after 90 min.

4) To find environmental optimum in 5~12V and 0~120min electrolysis, simulated annealing was used. Comparing the solution from simulated annealing with the global optimum, simulated annealing can give quick and accurate solution (43% in 0.5V and 5min range, 85% in 1V and 10min range). When optimization process deals with a large number of variate or a wide searching range, simulated annealing will solve the optimization problem effectively.

5) Because the environmental optimum searching method is based on the data from experiment or in-field operation, many experiments or in-field operation should be executed. To overcome this respect, thermodynamic and electrochemical modelling should be developed together.

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