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ปีการศึกษา 2550

# MODELING AND OPTIMIZATION OF A RINSING PROCESS FOR MACHINERY PRODUCTION

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Chemical Engineering
Department of Chemical Engineering
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| | |
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| Thesis Title | MODELING AND OPTIMIZATION OF A RINSING PROCESS FOR MACHINERY PRODUCTION |
| By | Miss Soottiwan Noksa-nga |
| Field of Study | Chemical Engineering |
| Thesis Advisor | Associate Professor Paisan Kittisupakorn, Ph.D. |

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สุทธิวรรณ นกสง่า : การสร้างแบบจำลองและออปติไมซ์กระบวนการล้างสำหรับการผลิตเครื่องจักรกล. (MODELING AND OPTIMIZATION OF A RINSING PROCESS FOR MACHINERY PRODUCTION) อ. ที่ปรึกษา : รศ.ดร. ไพศาล กิตติศุภกร
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อุตสาหกรรมการผลิตเครื่องจักรกล เป็นอุตสาหกรรมที่มีความสำคัญมากอย่างหนึ่งของประเทศ กระบวนการล้างนับเป็นกระบวนการหลักกระบวนการหนึ่งในอุตสาหกรรมเครื่องจักรกล ซึ่งเป็นกระบวนการที่มีการใช้น้ำในปริมาณมาก การลดปริมาณการใช้น้ำในอุตสาหกรรมนี้ส่วนใหญ่จะทำการศึกษาวิจัยเกี่ยวกับการออกแบบกระบวนการล้าง แต่สำหรับการศึกษาเกี่ยวกับสภาวะที่เหมาะสมของกระบวนการล้างนั้นยังมีน้อย ดังนั้นในงานวิจัยนี้ได้ทำการศึกษาการหาสภาวะที่เหมาะสมของอัตราการไหลของน้ำล้าง ทั้งนี้การได้มาซึ่งค่าที่เหมาะสมนั้นจะต้องทำการหาแบบจำลองทางคณิตศาสตร์ของกระบวนการล้างโดยใช้หลักการสมดุลมวลสาร ด้วยการศึกษาการจำลองกระบวนการล้างจะทำให้ทราบการเปลี่ยนแปลงของกระบวนการในรูปของของค่าความเข้มข้นของกรดและด่าง โดยขึ้นกับอัตราการไหลของปริมาณน้ำ การหาคำตอบสำหรับหาสภาวะที่เหมาะสมดำเนินการโดยใช้โปรแกรม MATLAB ซึ่งพบว่าในสภาวะที่เหมาะสมจะสามารถลดอัตราการไหลของปริมาณน้ำล้างโดยรวมจากวิธีการดำเนินการในปัจจุบันได้ถึง 9.8 เปอร์เซ็นต์

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SOOTTIWAN NOKSA-NGA : MODELING AND OPTIMIZATION OF A RINSING PROCESS FOR MACHINERY PRODUCTION THESIS ADVISOR : ASSOC. PROF. PAISAN KITTISUPAKORN, Ph.D.,74 pp.

A machinery production sector is one of the most important industrial sectors in Thailand. A rinsing process in the machinery production has been considered as a large amount water consumed process. Therefore, to reduce water consumption, most enterprises have carried out the development of rinsing processes but the optimization of these rinsing processes has been rarely studied. This work studies the optimization of a rinsing process in the machinery production to determine the optimal water consumption in the rinsing process. To achieve this, mathematical models of the process have been developed based on mass balances. With these models, simulation study has been carried out to find out the behavior of the process in terms of the concentration of acid and base in rinse water with respect to water flow rate. Then the optimization problem has been formulated and solved using written programs based on MATLAB. The results have shown that the optimal water flow rate is less than the original one of 9.8 percent.

Department: Chemical Engineering Student’s Signature: ...............................

Field of Study: Chemical Engineering Advisor’s Signature: ...............................

Academic Year 2007

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# LIST OF ABBREVIATIONS

## Rinsing Process

| | |
|---|---|
| $A$ | $Q_R/D$ |
| $a_n$ | Coefficient of imperfect mixing |
| $b_n$ | $1 - a_n$ |
| $C_0$ | Concentration in initial bath (gram/litre) |
| $C_n$ | Concentration at workpiece after rinsing in the nth rinse tank (mole/litre) |
| $C_p$ | Concentration in chemical bath (gram/litre) |
| $C_R$ | Concentration of fresh rinse water (mole/cubic meter) |
| $D$ | Volume of solution dragged out by the workpiece in the unit time (l/sec) |
| $k$ | $k$ effective mixing rate , $k= V/D$ (1/sec.) |
| $Q_R$ | Volume of fresh rinse water (cubic meter /hour) |
| $t$ | Time (sec.) |
| $V$ | Rinsing tank volume (cubic meter) |
| $Z_n$ | Average final concentration in the nth rinse tank (mole/litre) |

## Mathematic Modeling

| | |
|---|---|
| $a_n$ | Coefficient of imperfect mixing |
| $b_n$ | $1 - a_n$ |
| $C_A$ | Concentration in acid bath (mole/cubic meter) |
| $C_B$ | Concentration in alkaline bath (mole/cubic meter) |

# LIST OF ABBREVIATIONS

## Mathematic Modeling

| | |
|---|---|
| $C_n$ | Concentration at workpiece after rinsing in the n$^{th}$ rinse tank (mole/cubic meter) |
| $D$ | Volume of solution dragged out by the workpiece in the unit time (cubic meter /sec) |
| $F_n$ | Volume of fresh water to n$^{th}$ rinsing tank (cubic meter /sec) |
| $k$ | $k$ effective mixing rate , $k$= $V/D$ (1/sec.) |
| $t$ | Time (sec.) |
| $V_n$ | The n$^{th}$ rinsing tank volume (cubic meter) |
| $Z_n$ | Average final concentration in the n$^{th}$ rinse tank (mole/litre) |

## Optimization

| | |
|---|---|
| $H$ | Hamiltonian function |
| $J$ | Performance index |
| $n_X$ | Terminal state |
| $T$ | Final time |
| $u_t$ | Input function |
| $X_0$ | Initial state |
| $X_t$ | *S*tate variable |
| $\lambda$ ,$\upsilon$ | Lagrange multiplier |

# CHAPTER I

# INTRODUCTION

## 1.1 Importance and reasons for research

Metal finishing is one of the major industry sectors in the country. Many industries use metal finishing in their manufacturing processes including automotive, electronics, hardware, jewelry, appliances, tires, and telecommunications. Without metal finishing, products made from metals would last only a fraction of their present lifespan because of corrosion and wear. More over, metal finishing is used to enhance electrical properties, to form and shape components, and to enhance the bonding of adhesives or organic coatings. At the same time, it consumes many of resources, especially, water.

In the metal finishing, rinsing is necessary process to remove a clinging film of process solution from workpieces by substituting in its place an innocuous film of water. The purer the water, the more effective the rinsing. Thus, it is necessary to dilute the clinging film of former solution. From rule of thumb the dilution ratio of 1,000:1 is a good starting point. However this ratio is not the answer, it still has a high volume of water usage and occurs a high discharge of wastewater. The changing time, the reusing or recycling of rinsewater and the use of counterflow rinsing having been considered.

As seen from the background data, a motivation of research can be classified as follows. First, a rinsing process which has a high efficiency of washing and low water consumption is improved by using a mathematical model. Second, an environmental aspect from a rinsing process in the metal finishing is decreased.

This research is aimed at finding a mathematical model for rinsing process in the metal finishing industry. This model can be used studied a dynamic of rinsing water, design and simulation the rinsing process with saved water consumption and low a discharge of wastewater. Furthermore, the model can be used to design a control system for the rinsing process.

## 1.2 Research objectives

The objectives of this research are as follows:

1. Create a mathematical model of a rinsing process
2. Find an optimal model for decreasing water consumption and discharge of wastewater in the rinsing process.

## 1.3 Scopes of Research

The scopes of this research are presented in the following:

1. The data for developed mathematical model is provided from the plant.
2. The optimal model for decreasing water consumption and discharge of wastewater has no implementation.
3. Matlab application software is used for modeling and simulation.

## 1.4 Contribution of research

1. A mathematical model of a rinsing process for the metal finishing industry will be created.
2. The optimal rinsing process will be designed for decreasing water consumption and discharge of wastewater.

## 1.5 Methodology

The methodology of this research are

1. Research and review the rinsing process from the document
2. Study the rinsing process in the factory.
3. Make a mathematical model that is representative of this system.
4. Compare the simulation result with the plant data
5. Improve the mathematical model and compare the result.
6. Find the optimal model for decreasing water consumption and discharge of wastewater by using the developed model.
7. Summarize and make a document

## 1.6 Overview of This Thesis

The organization of this research is as follows:

Chapter II presents the literature review in modeling the rinsing process and the applications of DO in rinsing process.

Chapter III describes the theory of metal finishing, mathematic modeling, and optimization .

Chapter IV describes the methodologies of the research

Chapter V present the result and application of optimization approach in rinsing process.

Finally, the conclusions and the recommendations for future work are given in Chapter VI.

# CHAPTER II

# LITERATURE REVIEW

This chapter is divided two parts. First part, it describes a modeling of rinsing process in many industrial sectors, which is used a base model to develop for machinery production industry. Second part, it reviews an application of dynamics optimization in chemical engineering filed.

## 2.1 Modeling of Rinsing Process

Giebler E (2004) proposed a steady state model of counter-current rinsing systems. The model is formulated in a compact matrix form that, in contrast to conventional descriptions, can be applied to a wide range of special cases by use of adequate matrices and vectors. The necessary formation rules are presented for a simple cascade rinsing system and for rinsing systems with pre-rinsing, imperfect mixing and spray rinsing.

W. Silalertruksa, P. Kittisupakorn and S. Boonyanant (2001) applied a rinsing model in Zinc and Chromium plating industry and used it to optimize minimum fresh water consumption. The result found that factory could be decreased excess water usage in rinsing process by proper rinse water flow rate control. From optimize technique obtained 7 percent reduction of fresh water usage.

Fullen, W. John (2000) developed a model for rinse water reduction. The first step in making rinse water use reductions is to determine the required amount of water for any specific process. The difference between common current practices and how much water is needed define over half of the potential rinse water reduction obtainable. Incoming water flow rates can be estimated by developing mathematical models based on means of mass balances. Model for double counter current and single heated rinse tank is formulated at steady state and transient conditions.

Lou, H.R. and Huang, Y.L. (1999) proposed a model-based dynamic simulator for cleaning and rinsing. This research presents a set of dynamic models for characterizing the cleanness of parts, the change of chemical concentrations in cleaning tanks, and the pollution level in rinsing tanks. The models have been implemented as a dynamic simulation tool. The tool is used for platers to check the operational status of their plating lines, to determine optimal settings of chemical and rinsing water, to identify waste reduction opportunities, and to estimate economical and environmental incentives.

Torsten Bohlin (1994) used a grey box identification to find a model of strip steel rinsing process. The purpose of the study is twofold: First, to find a working procedure for carrying out interactive system identification, especially using the grey box identification tool. The procedure comprises a sequence of hypothesis testing and parameter fitting, and involves the designer closely in the interactive ‘loop’ to contribute ‘engineering sense’. Final, to explain the choice between internal-noise, external-noise, or no-noise (deterministic) structures, in particular whether the result may be worth the effort of using optimal state-variable filtering.

B. Sohlberg (1993) studied an optimal control of a steel strip rinsing process. Modeling and identification of the process is based on knowledge about the process and measured data from the process. In the model, the worn parts are modeled explicitly and estimated on line by an Extended Kalman Filter. The process is influenced by changing production variables. It is measurable but not controllable. The model is expressed in a discrete state space form, which makes the model suitable for optimal control.

Amadi, Sebastian I. (1985) studied a modeling and simulation of rinsing process for a printed circuit board production. A typical rinse process in a plating shop is modeled and simulated on a computer. Mathematical equations were developed for a rinse process whose configuration includes a stagnant drag-out rinse and a final constant volume and variable volume spray rinse. The model equations were simulated on the computer. Factors that affect final effluent discharge were also considered

## 2.2 Dynamic Optimization

Victor M. Zavalaa, Antonio Flores-Tlacuahuac and Eduardo Vivaldo-Lima (2004) applied the dynamic optimization concept in a polyurethane copolymerization reactor. A kinetic–probabilistic model is used to describe the nonlinear step-growth polymerization of a mixture of low- and high-molecular-weight diols, and a low-molecular-weight diisocyanate. The main objective is the maximization of the molecular weight distribution (MWD) under a desired batch time, subject to a large set of operational constraints, while simultaneously avoiding the formation of polymer network (gel molecule). It was found that process operation is greatly enhanced by the semibatch addition of 1,4-butanediol and diamine, and the manipulation of the reactor temperature profile, allowing to obtain high molecular weights while avoiding the onset of the gelation point.

Richard Fabera, Tobias Jockenh ovelb and George Tsatsaronisc (2004) presented an approach for the dynamic optimization of energy and chemical engineering processes with the simulated annealing algorithm. They developed an optimization methodology, which finds optimal control strategies requiring a minimum of user input. The methodology we propose uses rigorous dynamic Simulink models based on first principles in a black-box approach. The presented approach based on the SA algorithm has the potential to find the global optimum and it does not need any additional information than the dynamic model itself.

Bing Zhang, Dezhao Chena and Weixiang Zhaoc (2004) sloved dynamic optimization problems of chemical process with numerical methods, a novel algorithm named iterative ant-colony algorithm (IACA). The main idea was iteratively execute ant-colony algorithm and gradually approximate the optimal control profile. The results of the case studies demonstrated the feasibility and robustness of this novel method. IACA approach can be regarded as a reliable and useful optimization tool when gradient is not available.

Joan Cristian Treleaa, Mariana Titicab and Georges Corrieua (2004) presented the possibility of obtaining various desired final aroma profiles and reducing the total process time using dynamic optimization of three control variables: temperature, top pressure and initial yeast concentration in the fermentation tank. The optimisation is based on a sequential quadratic programming algorithm, on a dynamic model of the alcoholic fermentation and on an aroma production model.

B. Chachuat, N. Roche and M.A. Latifi (2001) applied dynamic optimization technique in small size wastewater treatment plants. The problem is stated as a hybrid dynamic optimization problem, which is solved using a gradient-based method. They found minimization of the energy consumption and satisfy discharge requirements under specified constraints with process and physical constraints. The comparison between usual rule-based control policies and optimized strategies showed that the optimized aeration profiles lead to reductions of energy consumption of at least 30%.

# CHAPTER III

# THEORY

This chapter presents the theory that involves this research. The organization of this chapter is as follows: the brief background of metal finishing, the basic concept of Rinsing process, mathematic modeling of rinsing process and the optimization.

## 3.1 Metal finishing

Metal finishing alters the surface of metal products to enhance:

- Corrosion resistance
- Wear resistance
- Electrical conductivity
- Electrical resistance
- Reflectivity and appearance (e.g., brightness or color)
- Torque tolerance
- Solderability
- Tarnish resistance
- Chemical resistance
- Ability to bond to rubber (e.g., vulcanizing)
- Hardness

Metal finishers using a variety of materials and processes to clean, etch, and plate metallic and nonmetallic surfaces to create a workpiece that has the desired surface characteristics.

Generally, objects to be finished undergo three stages as follows.

### 3.1.1 Surface preparation

Platters clean the surface of the workpiece to remove greases, soils, oxides, and other materials in preparation for application of the surface treatment. The operator typically uses detergents, solvents, caustics, and other media first in this stage and then rinses the workpiece. Next, an acid dip is used to remove oxides from the workpiece, which is then rinsed. The part is now ready to have the treatment applied.

### 3.1.2 Surface treatment

This stage involves the actual modification of the workpiece surface including plating. The actual finishing process includes a series of baths and rinses to achieve the desired finish. For example, a common three-step plating system is copper-nickel-chrome. The copper is plated first to improve the adhesion of the nickel to the steel substrate and the final layer, chrome, provides additional corrosion and tarnish protection. Following the application of each of the plate layers, workpieces are rinsed to remove the process solution. The final step in the process is drying. This step can consist of simple air drying or a more complex system such as forced air evaporation or spin dry.

### 3.1.3 Post treatment

The workpiece, having been plated, is rinsed and further finishing operations can follow. These processes are used to enhance the appearance or add to the properties of the workpiece. A common example of a post-treatment process is heat treating to relieve hydrogen embitterment or stress.

## 3.2 Rinsing process

The rinsing process is the removal of a harmful clinging film of process solution from a workpiece by substituting in its place an innocuous film of water. Efficient rinsing then comprises achieving the desired end while expending as little work or “effort” as possible. In general, it is necessary to thoroughly rinse the work between the various treatment stages. For example, ware carrying off an unrinsed film of alkaline cleaning solution would quickly contaminate a subsequent acid pickle, which if in its turn went unrinsed would rapidly contaminate the plating bath. Subjecting the work to a high level of contamination in the rinse tanks can also cause passivation of the work surface or encourage precipitation of reaction products on the work. And if the final processing solution is not properly rinsed, salt spotting will occur which may cause etching or be otherwise harmful, and in any case will be unattractive. Thus it is necessary to dilute the clinging film of process solution to such an extent that problems such as salt staining and contamination of subsequent processes are limited to manageable levels.

The design of rinsing tank and water flow is very importance. Rising tank can be connected in many ways and can design in single or multiple stages.

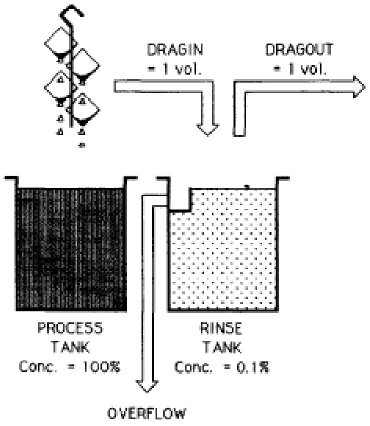

**Figure 3.1** Single Stage Rinsing

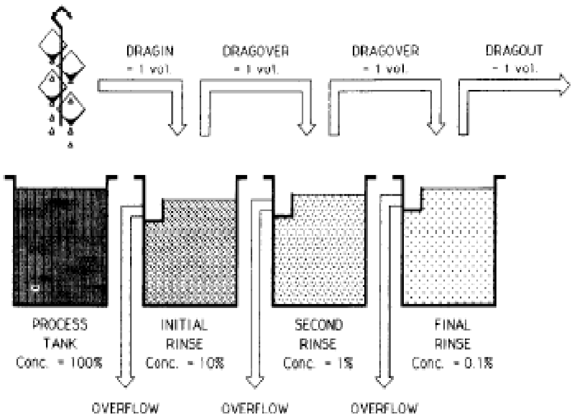

**Figure 3.2** Multiple Stage Rinsing

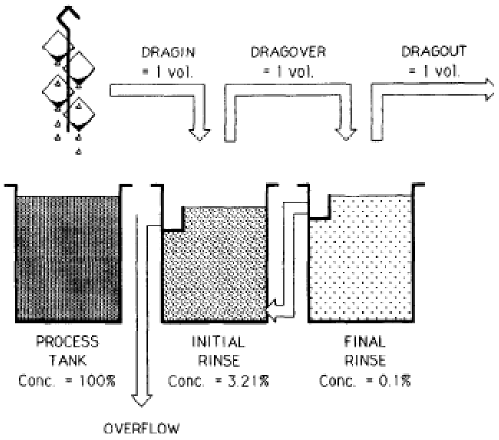

**Figure 3.3** Counterflow Rinsing

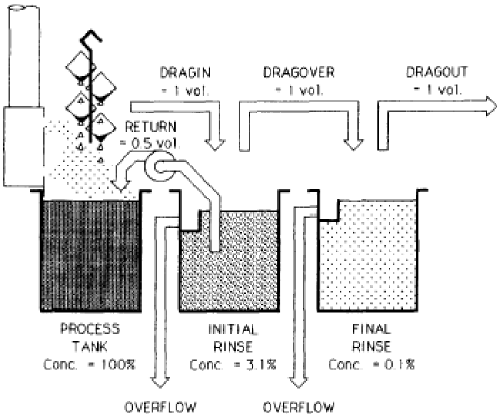

**Figure 3.4** Rinsing with Recovery

Care should go into the design of rinse tanks so that they may operate as efficiently as possible. The overflow weir must be level and full length to minimize short-circuiting; lacking a level overflow weir, the fresh water added to the tank will take the path of least resistance rather than mixing thoroughly with the contents of the tank. This would be wasteful of water since the overflowing wastewater would then be less concentrated than the tank contents. Equally important to promote good mixing is for the fresh water inlet to be brought to the bottom of the tank and be distributed via a perforated pipe. As noted in the earlier discussion of counterflow rinsing, it is extremely important that sufficient gravity head exist, and the details of the design be properly executed, to preclude a backwash of dirty water from the initial rinse to the final rinse

## 3.3 Mathematic Modeling

Zofia Buczko [1992] presented a mathematical model about rinsing process. He required estimating the contaminants on the workpiece surface after rinsing. The complete-mixing theory is the simplest but is far from practices. However, it is still the basic assumption made in all rinsing equation. Some attempts at analysis of the concentration on the workpiece after rinsing have been made. They were mainly based on diffusion and convection theories. The mathematical expressions derived were related to ideal conditions, which cannot exist in a real system.

When analysis the results of the laboratory investigations, it has been concluded that when modeling the rinsing process mathematically it is not possible to apply diffusion or convection equations. The hydrodynamics of these processes is much more complicated to express by simple physical theory.

Because of contrary to the assumption of complete equalization of concentration at the product and in a rinsing tank during the washing process, he assumed that an average concentration $C_n$ at the workpiece after rinsing in the $n^{th}$ rinse tank is a combination of the concentration $C_{n-1}$ of the inlet solution (concentration at the workpiece after rinsing in the $(n-1)^{th}$ rinse tank) and an average final concentration $Z_n$ the tank taken in suitable proportions. The average concentration of the workpieces can be described by

$$C_n = a_n C_{n-1} + b_n Z_n \tag{3.1}$$

The coefficient $a_n$ indicates the contribution from the initial concentration to the average final concentration at a workpiece after rinsing. It is called the imperfect-mixing coefficients (IMCs) with values from 0 to 1. The IMCs are $a_n=0$ in the case of perfect mixing. It also depends on the rinsing techniques and character of the withdrawn film on the work surface.

To formulate the rinsing equation, an additonal assumption of continuous-rinsing operation has also been made. In fact the rinsing process in a given rinse is not continuous but stepwise; workpieces are immersed within pre-determined time intervals. If the volume of drag-out solution is small with respect to the rinse volume, the concentration variations in the rinses can be treated as pseudo-continuous with time and differential calculus can be applied for calculation. Under this assumption the computational mass balance equations have been derived previously and are usually used in perfect-mixing rinsing calculations.

A differential equation for the $n^{th}$ non-flow rinse is derived, under the assumption that for each rinse the drag-out D is the same bath before and after rinsing:

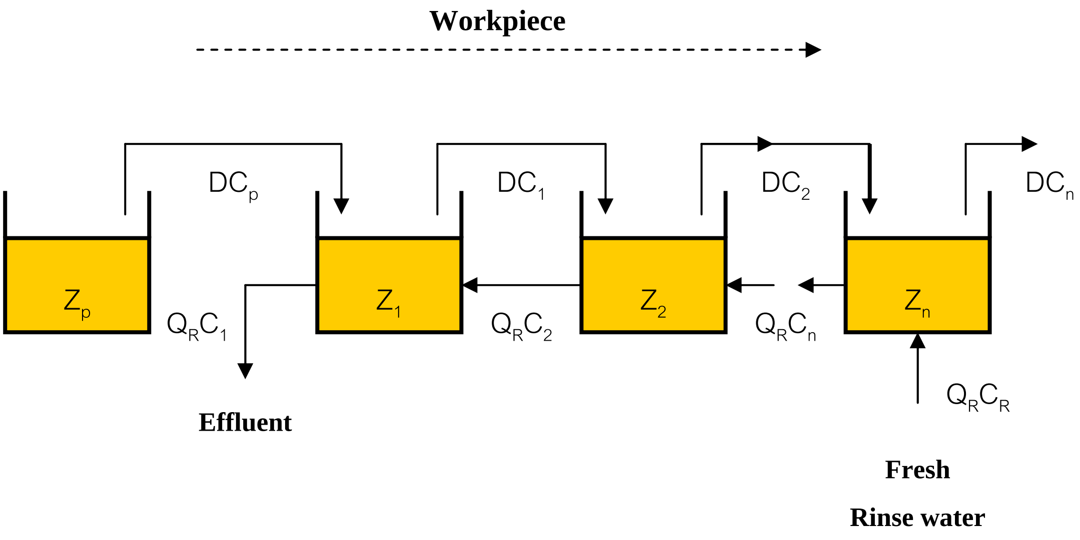

**Figure 3.5** Series type of cascade rinsing

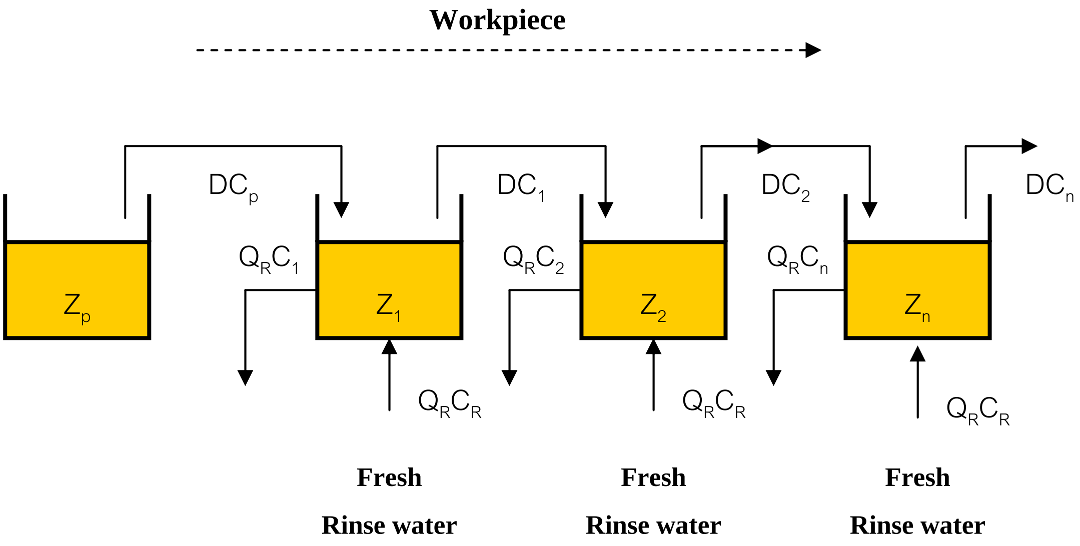

**Figure 3.6** Parallel type of cascade rinsing

Series type $$C_n = C_p\left[\frac{A-1}{A^{n+1}-1}\right] \qquad (3.2)$$

Parallel type $$C_n = C_p(1+A^n) \qquad (3.3)$$

Where n = number of rinse tank, $A = \frac{Q_R}{D}$

with the initial condition $Z_{n(t=0)}=0$, where V is the volume of the rinsing bath and $C_0$ is the concentration of the process of bath drag into the first rinse, which is invariant in time.

For incomplete mixing, substitution of equation (3.2) into (3.3) and rearrangement one can obtain the following set of differential equations

$$\left.\begin{array}{l} kb_nC_{n-1}=\dfrac{dZ_n}{dt}+kb_nC_n \\[2ex] C_n=aC_{n-1}+(1-a_n)Z_n \end{array}\right\} n=1,2,3,... \tag{3.4}$$

Where $b_n=1-a_n$, $k=\dfrac{D}{V}$

One can find that the solution is of the form

$$\left.\begin{array}{l} C_n=C_0\left(1-\sum\limits_{j=1}^{n}\alpha_n^j\exp(-kb_jt)\right) \\[2ex] Z_n=C_0\left(1-\sum\limits_{j=1}^{n}\beta_n^j\exp(-kb_jt)\right) \end{array}\right\} n=1,2,3,... \tag{3.5}$$

Where the recurrent form for the coefficients $\alpha_n^j$ and $\beta_n^j$ is

$$\left.\begin{array}{l} \beta_n^j=1 \\ \alpha_n^j=b_1 \end{array}\right\} \text{for } n=1, j=1$$

$$\left.\begin{array}{l} \beta_n^j=\dfrac{b_n}{b_n-b_j}\ \alpha_{n-1}^j \\[2ex] \alpha_n^j=\alpha_n\alpha_{n-1}^j+b_n\beta_n^j \end{array}\right\} \text{for } n>1,\ j=1,...,n\text{-}1$$

$$\tag{3.6}$$

$$\left.\begin{array}{l} \beta_n^n=1-\sum\limits_{i=1}^{n-1}\dfrac{b_n}{b_n-b_j}\ \alpha_{n-1}^j \\[2ex] \alpha_n^n=b_n\beta_n^n \end{array}\right\} \text{for } j=n$$

In case perfect mixing (a=0 and b=1), it is easy to obtain an equation.

$$C_n = C_0\left(1-\exp(-kt)\sum_{j=0}^{n-1}\frac{(kt)^j}{j!}\right) \tag{3.7}$$

## 3.4 Optimization of Rinsing Process

Optimization is a method to obtain the best solution under constraint of system or process. The objective function is identified the best solution. It is determined from asset, operation cost, production, net profit and others. The value of the objective function can be found by adjust decision variable of system. This variable maybe is size of equipment and operating condition of process such as pressure, temperature and flow rate etc. Adjusting this variable must consider under constraint of operation as purity of product, feasibility of model and the relationship of variable.

The optimization consists of four parts as following.

### 3.4.1 Process Model

The objective of model is to identify the solution of objective function and the position of constraint. A reliable model is necessary for calculation which can be divided as mathematical model and actual process

### 3.4.2 Objective Function

The objective function means a equation or group of equation which are formulated for calculation. The calculations have finding minimum value or finding maximum value. The objective function for optimization has various forms such as annual cost, net benefit, production time and energy consumption rate etc.

### 3.4.3 Constraint

The optimization always has constraints of each system for finding the solution in feasible region of decision variable. The feasible region of decision variable is determined with constraint which is formulated from mass balance, energy balance, equipment design and property of matter.

Natural condition of physical production is express area or feasible region and the solution locates in this region. The constraint has two forms as following.

1. Equality constraint is a constraint which has a sign (=) in the equation. The equality constraint is an equation which indicates process and product limitation such as mass balance, energy balance and purity of product.

2. Inequality constraint is a constraint which has sign (=), (<) ,(>), (≤), (≥) or (≠) in the equation The inequality constraint is an equation which indicates limitation of design and other limitation such as mole fraction, no negative value of flowrate and minimum of production rate.

### 3.4.4 Decision Variable

Decision variable is adjust variable for finding maximum or minimum of objective function value and affecting objective function such as temperature, pressure, flow rate, concentration and reactor size. In the practicality, decision variable is set point for process control system.

The optimization problem can be classified two categories as follows

1. Static optimization is the process of minimizing or maximizing the cost or benefits of some objective function for one instant in time only.

2. Dynamic optimization is the process of minimizing or maximizing the cost or benefits of objective function over a period of time.

Characteristics of dynamics optimization problems can be divided that

#### ***3.4.4.1 Free Dynamic Optimization***

- *Discrete Time*

We focus on the problem of controlling the system

$$x_{i+1} = f(x_i, u_i) \qquad i = 0,\dots,N\text{-}1 \qquad x_0 = \underline{x}_0 \tag{3.8}$$

Such that the costs function

$$J = \phi(x_N) + \sum_{i=0}^{N-1} L(x_i, u_i) \tag{3.9}$$

This is minimized. The solution to this problem is a sequence of control actions or decisions, $u_i = 0,\dots N-1$. Knowing the sequence $u_i = 0,\dots N-1$, the solution is the path or trajectory of the state and the costate. The problem is specified by the functions $f$, $L$ and $\phi$, the horizon $N$ and the initial state $\underline{x}_0$.

- *Continuous Time*

Consider the problem related to finding the input function $U_t$ to the system

$$\dot{x} = f_t(x_t, u_t) \qquad x_0 = \underline{x}_0 \qquad t \in [0, T] \tag{3.10}$$

such that the costs function

$$J = \phi_T(x_T) + \int_0^T L_t(x_t, u_t)dt \tag{3.11}$$

Which minimized. Here the initial state $\underline{x}_0$ and final time $T$ are given (fixed). The problem is specified by the dynamic function, $f_t$, the scalar value functions $\phi$ and $L$ and the constants $T$ and $\underline{x}_0$.

The problem is an optimization of (3.10) with continuous equality constraints. Similarly to the situation in discrete time, we here associate a $n$-dimensional function, $\lambda_t$, to the equality constraints, $\dot{x} - f_t(x_t, u_t)$. Also in continuous time these multipliers are denoted as costate or adjoint state. In some part of the literature the vector function, $\lambda_t$, is denoted as influence function.

### *3.4.4.2 Dynamic Optimization with End Points Constraints*

Consider the discrete time system (for $i = 0,1,\ldots,N-1$)

$$x_{i+1} = f(x_i, u_i) \qquad x_0 = \underline{x}_0 \tag{3.12}$$

The cost function

$$J = \phi(x_N) + \sum_{i=0}^{N-1} L(x_i, u_i) \tag{3.13}$$

and the simple terminal constraints

$$x_N = \underline{x}_N \tag{3.14}$$

where $\underline{x}_N$ and $\underline{x}_0$ are given. In this simple case, the terminal contribution, $\phi$, to the performance index could be omitted, since it has not effect on the solution (except a constant additive term to the performance index). The problem consists of the system (3.12) from its initial state $\underline{x}_0$ to a (fixed) terminal state $\underline{x}_N$ such that the performance index, (3.13) is minimized.

The problem is specified by the functions $f$ and $L$ (and $\phi$), the length of the horizon $N$ and by the initial and terminal state $\underline{x}_0$, $\underline{x}_N$. We apply the usual notation and associate a vector of Lagrange multipliers $\lambda_{n+1}$ to each of the equality constraints $x_{i+1} = f(x_i, u_i)$. To the terminal constraint we associate, $\upsilon$ which is a vector containing $n$ (scalar) Lagrange multipliers.

- *Continuous Time*

In this section we consider the continuous case in which $t \in [0, T] \in R$. The problem is to find the input function $u_t$ to the system

$$\dot{x} = f_t(x_t, u_t) \qquad x_0 = \underline{x}_0 \tag{3.15}$$

such that the cost function

$$J = \phi_T(x_T) + \int_0^T L_t(x_t, u_t)dt \tag{3.16}$$

is minimized and the end point constraints in

$$\psi_T(x_T) = 0 \tag{3.17}$$

Here the initial state $\underline{x}_0$ and final time $T$ are given (fixed). The problem is specified by the dynamic function, $f_t$, the scalar value functions $\phi$ and $L$, the end point constraints through the function $\psi$ and the constants $T$ and $\underline{x}_0$.

# CHAPTER IV

# METHODOLOGY

This chapter presents the methodologies of research. The organization of this chapter is as follows

1. Study the rinsing process from the document and in the factory
2. Make a mathematical model that is representative of this system.
3. Compare and improve the simulation result with the plant data
4. To optimizes model for decreasing water consumption and discharge of wastewater

## 4.1 Rinsing Process in Machinery production

Rinsing Process of Machinery production which studied is in the first stage of metal finishing process ,surface preparation, can be described with process flow diagram (Figure 4.1- 4.2) as follows. Each of stage, work piece moving through series of baths containing chemicals, detergents, solvents, caustics, and other media used for surface cleaning. In each of these stages, rinsing is provided for removing the former process solution.

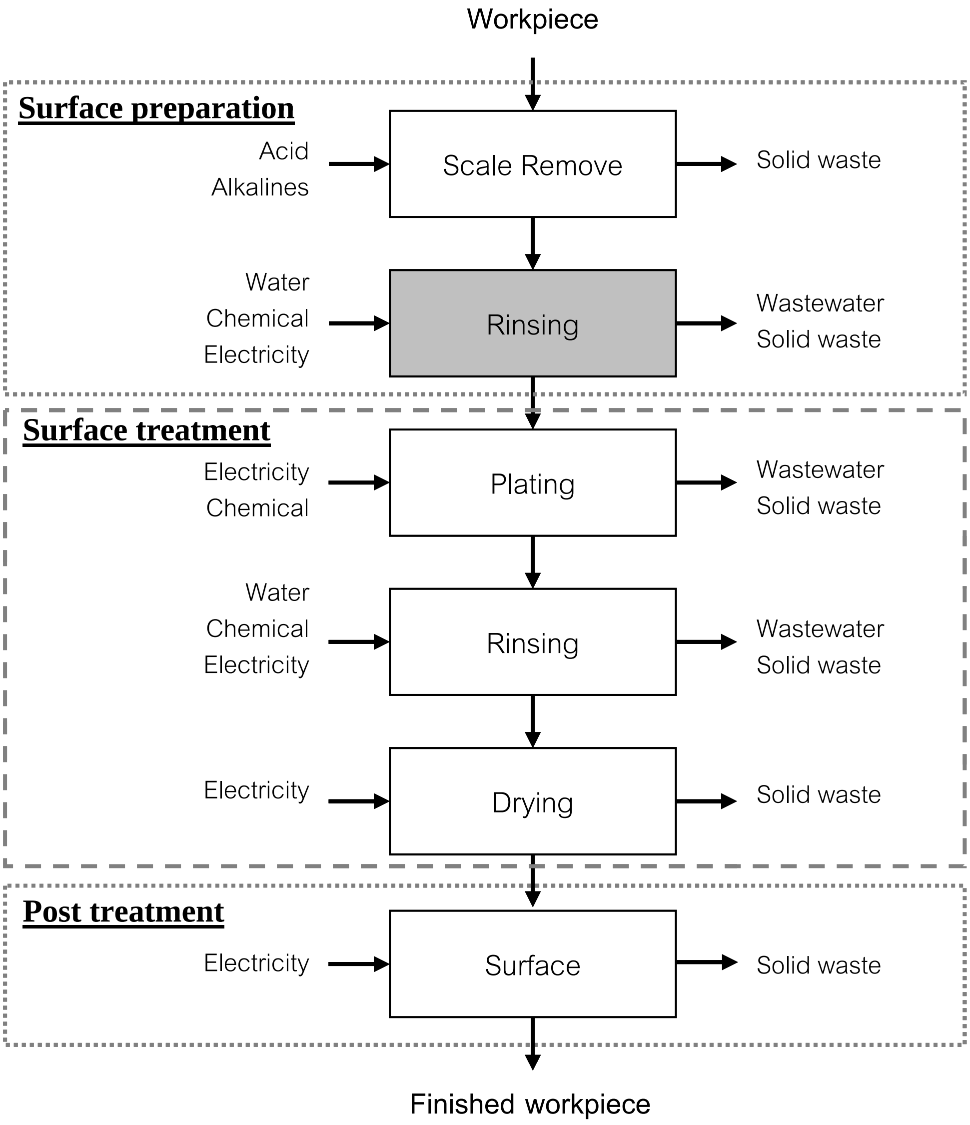

**Figure 4.1** Flow diagram of metal finishing process

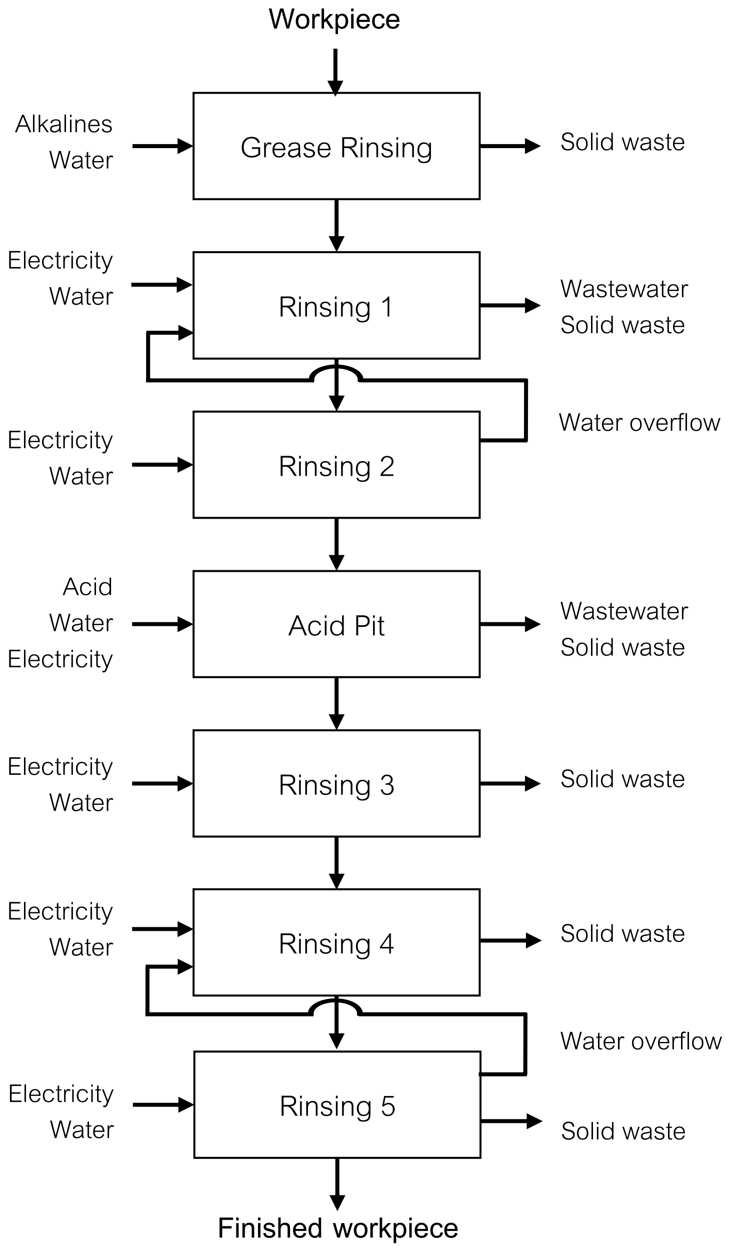

**Figure 4.2** Flow diagram of rinsing process

In the metal finishing, rinsing is necessary process to remove a clinging film of process solution from workpieces by substituting in its place an innocuous film of water. The process is comprised four part. First part is grease washing with alkaline solution. Second part is rinsing with fresh water by spray rinsing machine (Figure 4.3) in this part water used in counter current. Follow by rinse with caustics in a pit

(Figure 4.4) and rinsing with fresh water at last. The function of rinsing by injecting machine is removal a contaminant agent on parts. After finished of washing by machine, the water is discharged. Then the part is moved to a pit of caustic and to rinsing machine again for cleaning caustic agent contaminant before it is put in dryer machine.

**Figure 4.3** Spray rinsing machine

**Figure 4.4** Rinsing pit

## 4.2 Model for rinsing process

In this research, we interest to study rinsing process with cascade rinsing. This type is appropriate for available number of pit in factory. We apply rinsing model in previous chapter for rinsing system as follows

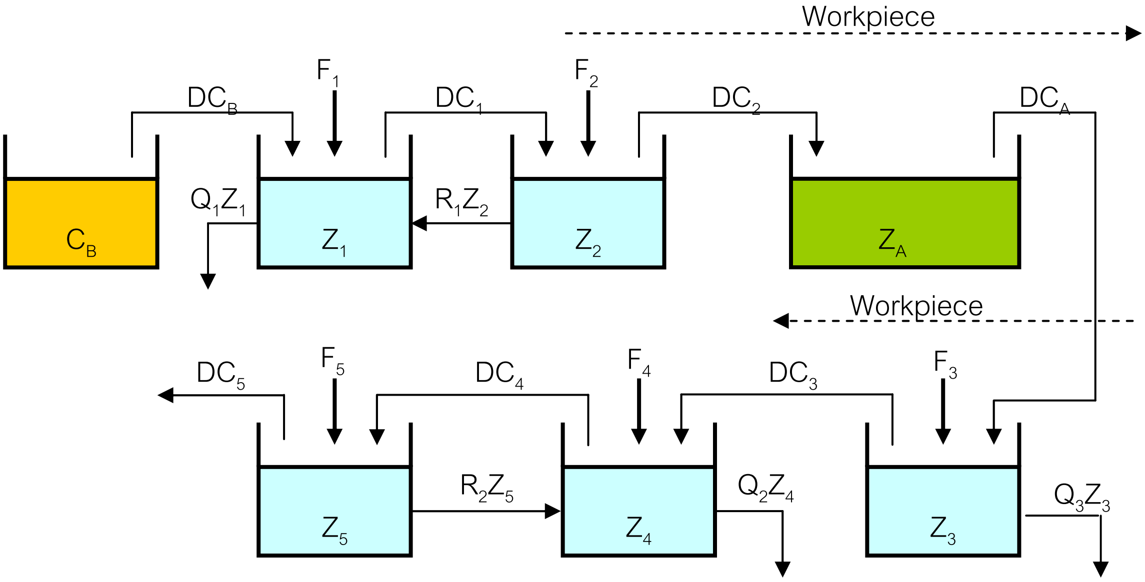

**Figure 4.5** Rinsing system in this research

From the equation of rinsing system (3.4) in previous section, we apply the assumption based on equal of volume of drag out and can express a mathematical model, which used to determine concentration of rinse water for each rinser as follows

$$\frac{dZ_1}{dt} = \frac{DC_B + F_1 C_F + b_2 R_1 Z_2 - DC_1 - b_1 (F_1 + R_1) Z_1}{V_1} \tag{4.1}$$

$$\frac{dZ_2}{dt} = \frac{DC_1 + F_2 C_F - DC_2 - b_2 R_1 Z_2}{V_2} \tag{4.2}$$

$$\frac{dZ_3}{dt} = \frac{DC_A - DC_3 - b_3 F_3 Z_3}{V_3} \tag{4.3}$$

$$\frac{dZ_4}{dt} = \frac{DC_3 + b_5 R_2 Z_5 - DC_4 - b_4 (F_4 + R_2) Z_4}{V_4} \tag{4.4}$$

$$\frac{dZ_5}{dt} = \frac{DC_4 - DC_5 - b_5 R_2 Z_5}{V_5} \tag{4.5}$$

Where $C_n = a_n C_{n-1} + b_n Z_n$

$b_n = 1 - a_n$ for n= number of rinser

The coefficient ($a_n$ and $b_n$) in equation (4.1) to (4.5) can be obtained from fitting curve between model and the experimental point.

## 4.3 Plant data collection

Plant data collection in this research can be described following. First, collecting fresh water flowrate at 1st to 5th tank every hour for 3 days.

Second, take example of solutions concentration in each tank, titrate alkali and acid tank with NaOH and $H_3PO_4$, calculating concentration to ion. Third, collecting drag out volume by draining solution form each of workpiece for an hour and collecting for 3 time a day and three days.

**Figure 4.6** Measure drag out from rinsing.

Finally, convert the measured concentration of solution in each tank at various of time . Calibrating curve by plot this data and vulue form theoretical mathematical model. Tuning theoretical mathematical model and determine the imperfect-mixing coefficients (IMCs) in each tank.

## 4.4 Simulation and optimization

Since the mathematical model at steady state can’t be expressed, dynamics optimization technique is applied to find an optimum value. In this research, we interests to find the optimum volume of rinsing water in each stage and an optimum volume of drag out under constraint with number of rinsing and limitation of cleaning agent concentration in the last of rinsing stage. We can generate the optimization problem in 2 case as following.

**Case 1 Determine the optimum volume of Fresh water in 2nd tank**

$$\min_{F_2} C_2 = a_2 C_1 + (1 - a_2) Z_2 \tag{4.6}$$

$$\text{Subject to } V_1 \frac{dZ_1}{dt} = DC_B + F_1 C_F + b_2 R_1 Z_2 - DC_1 - b_1 (F_1 + R_1) Z_1 \tag{4.7}$$

$$V_2 \frac{dZ_2}{dt} = DC_1 + F_2 C_F - DC_2 - b_2 R_1 Z_2 \tag{4.8}$$

$$Z_2^L \le Z_2 \le Z_2^U \tag{4.9}$$

$$Z_2 = Z_2(t_N) \tag{4.10}$$

$$F^L \le F \le F^U \tag{4.11}$$

**Case 2 Determine the optimum volume of Fresh water in 5th tank**

$$\min_{F_3, F_4, F_5} C_5 = a_5 C_4 + (1 - a_5) Z_5 \tag{4.12}$$

$$\text{Subject to } V_3 \frac{dZ_3}{dt} = DC_A - DC_3 - b_3 F_3 Z_3 \tag{4.13}$$

$$V_4 \frac{dZ_4}{dt} = DC_3 + b_5 R_2 Z_5 - DC_4 - b_4 (F_4 + R_2) Z_4 \qquad (4.14)$$

$$V_5 \frac{dZ_5}{dt} = DC_4 - DC_5 - b_5 R_2 Z_5 \qquad (4.15)$$

$$Z_5^L \le Z_5 \le Z_5^U \qquad (4.16)$$

$$Z_5 = Z_5 (t_N) \qquad (4.17)$$

$$F^L \le F \le F^U \qquad (4.18)$$

This problem is a dynamic optimization with end points constraints. The objective function is formulated from the relationship between the concentrations on workpiece at the last stage and the concentrations in the last tank. The constraints consist of mathematical model of concentration response in each stage, limitation of concentration in the last tank at final of rinsing cycle and lower-upper bound of the optimized variable (flowrate of fresh water at 2nd to 5th rinser ).

# CHAPTER V

# RESEARCH RESULT

This chapter divided the result in two parts as follows.

## 5.1 Model for rinsing process

In this part, we explain how to formulate the mathematical model. The model represents the dynamic response of concentration in five stages of rinsing, which we provide to improve the rinsing process in the machinery production.

### 5.1.1 Result of data collection

The example of concentration and fresh water flowrate collected from plant data shown in table 5.1 - 5.3 and figure 5.1 - 5.5

**Table 5.1** Concentration in tank $1^{st}$ – $2^{nd}$ from plant operating data.

| **Time** | **[OH-]** | | |
|---|---|---|---|
| | **Alkali** | **1st** | **2nd** |
| 10:00 | 9.50E-02 | 4.00E-05 | 2.00E-07 |
| 11:00 | 1.06E-01 | 4.77E-05 | 2.79E-07 |
| 12:00 | 9.10E-02 | 2.52E-05 | 4.27E-07 |
| 13:00 | 1.01E-01 | 1.60E-05 | 2.79E-07 |
| 14:00 | 9.20E-02 | 3.05E-05 | 2.53E-07 |
| 15:00 | 9.60E-02 | 3.18E-05 | 3.27E-07 |
| 16:00 | 1.00E-01 | 2.59E-05 | 3.59E-07 |

**Table 5.2** Concentration in tank 3rd – 5th from plant operating data.

| Time | [H+] | | | |
|---|---|---|---|---|
| | **Acid** | **3rd** | **4th** | **5th** |
| 10:00 | 1.84E-02 | 6.41E-04 | 3.79E-05 | 9.53E-07 |
| 11:00 | 1.83E-02 | 8.47E-04 | 4.68E-05 | 7.42E-07 |
| 12:00 | 1.89E-02 | 8.06E-04 | 5.12E-05 | 2.04E-06 |
| 13:00 | 1.87E-02 | 5.55E-04 | 5.12E-05 | 1.28E-06 |
| 14:00 | 1.82E-02 | 5.40E-04 | 3.79E-05 | 1.20E-06 |
| 15:00 | 1.81E-02 | 6.41E-04 | 6.41E-05 | 1.28E-06 |
| 16:00 | 1.86E-02 | 7.24E-04 | 5.12E-05 | 2.56E-06 |

**Table 5.3** Fresh water flowrate at various tank from plant operating data.

| Time | Fresh water flowrate ($m^3/s$) | | | | |
|---|---|---|---|---|---|
| | **F1** | **F2** | **F3** | **F4** | **F5** |
| 10:00 | 4.707E-04 | 2.829E-04 | 6.351E-04 | 5.850E-04 | 4.532E-04 |
| 11:00 | 4.558E-04 | 2.966E-04 | 6.424E-04 | 5.789E-04 | 4.460E-04 |
| 12:00 | 4.445E-04 | 2.883E-04 | 5.376E-04 | 5.412E-04 | 4.230E-04 |
| 13:00 | 4.318E-04 | 3.042E-04 | 6.095E-04 | 5.787E-04 | 4.290E-04 |
| 14:00 | 4.283E-04 | 2.977E-04 | 6.451E-04 | 5.589E-04 | 4.166E-04 |
| 15:00 | 4.376E-04 | 2.917E-04 | 6.185E-04 | 5.084E-04 | 4.877E-04 |
| 16:00 | 4.351E-04 | 2.799E-04 | 5.901E-04 | 5.430E-04 | 4.097E-04 |

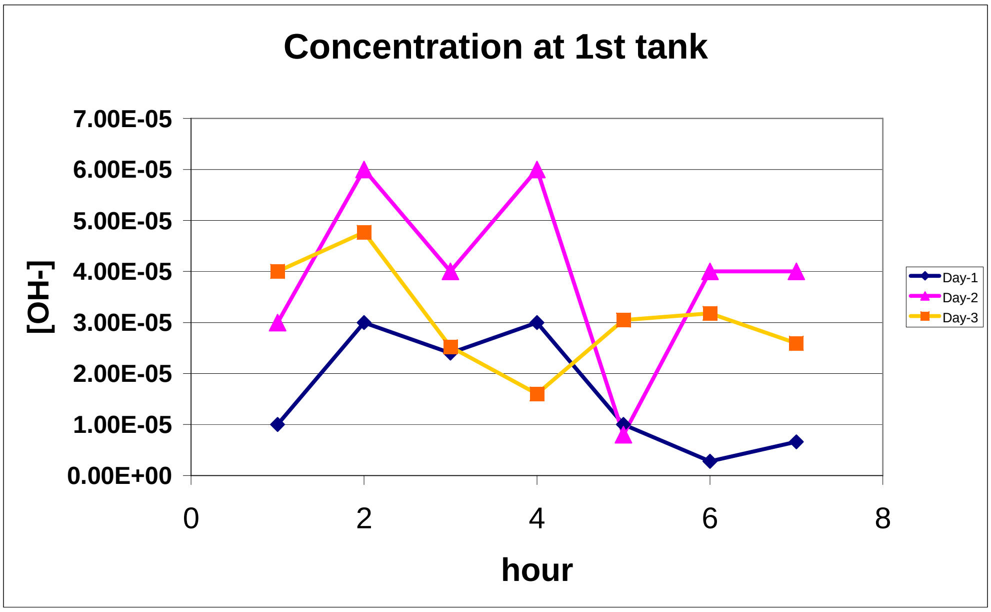

**Figure 5.1** Concentration of 1st tanks during 7 hours

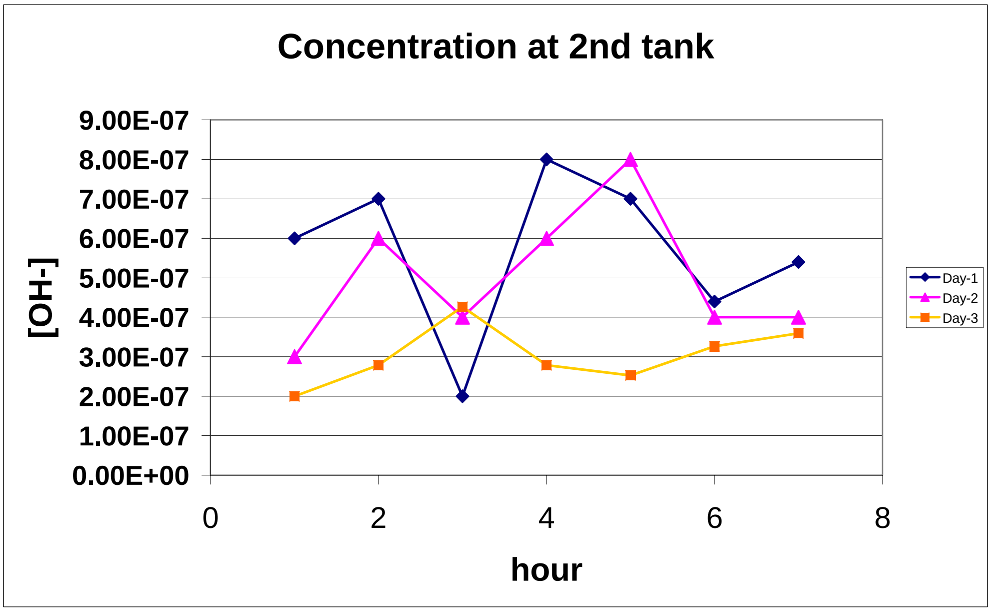

**Figure 5.2** Concentration of 2nd tanks during 7 hours

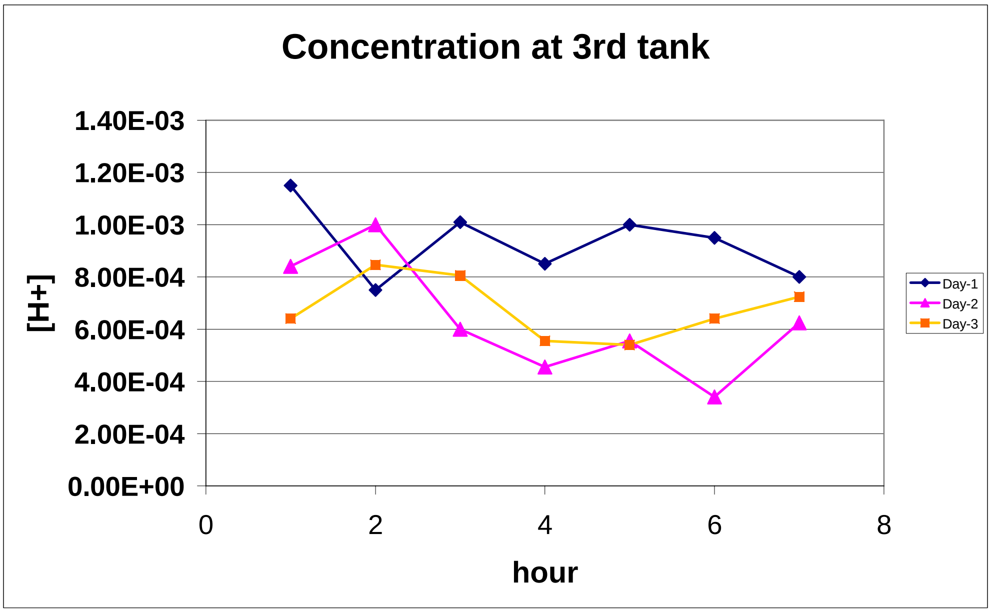

**Figure 5.3** Concentration of 3rd tanks during 7 hours

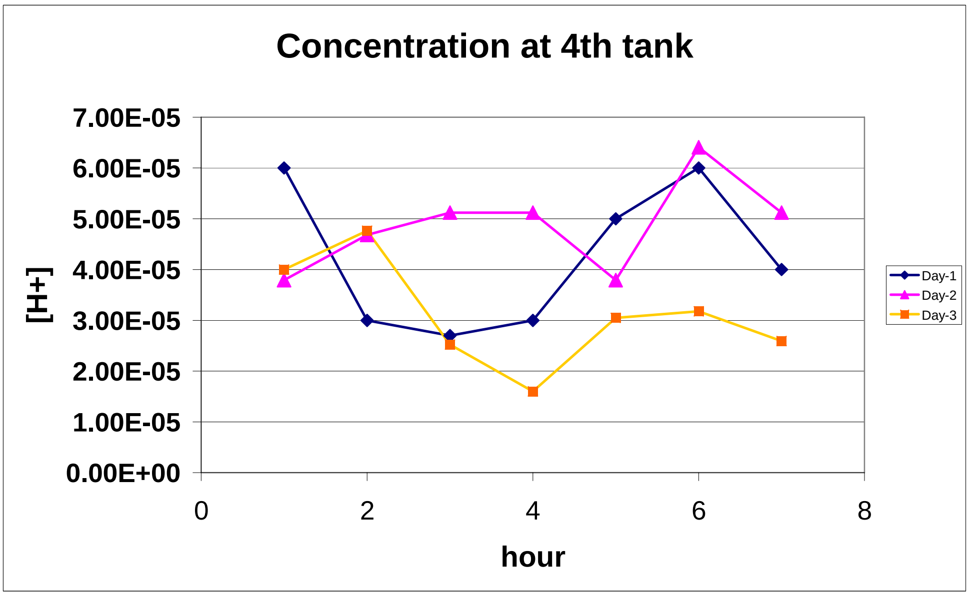

**Figure 5.4** Concentration of 4th tanks during 7 hours

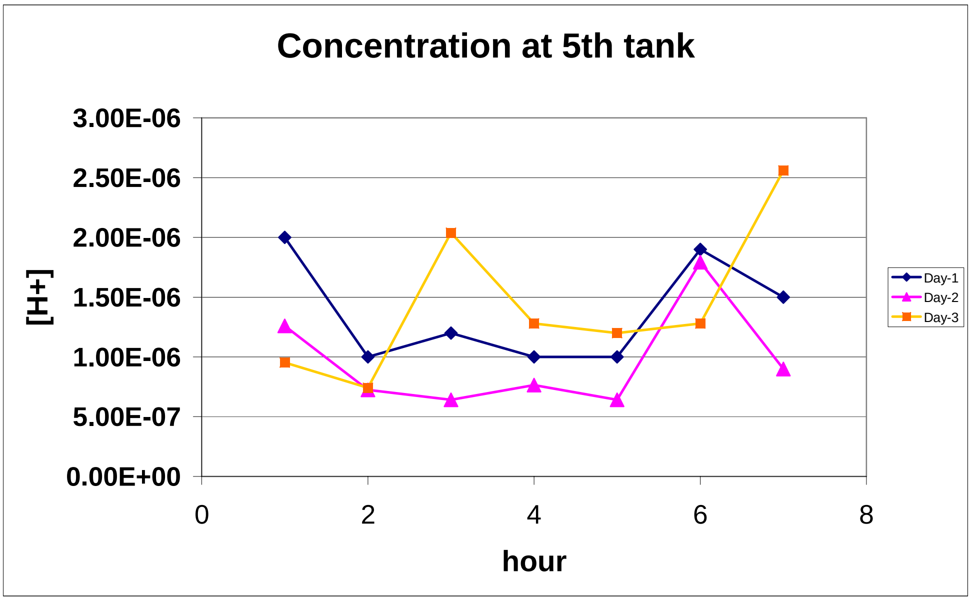

**Figure 5.3** Concentration of 5th tanks during 7 hours

The concentration data have been gathered from real plant operation in 3 days. In addition,fresh water flowrate also gather from real plant operation during a day.

## 5.1.2 Process parameter and initial condition

From the equation of rinsing model (Equation 4.1 to 4.18), the variables in these equations such $Z_n$, $C_n$, $V$ , $d$ …etc. with constant value are be determined from plant data as shown in table 5.4

**Table 5.4** Summary of plant operating data.

| List | Variables | Unit | Value |
|---|---|---|---|
| Initial of cleaning agent concentration<br>(Alkaline, NaOH) | $C_B$ | mol $[OH^-]/m^3$ | 9.50E-02 |
| Initial of cleaning agent concentration<br>(Acid, $H_3PO_4$) | $C_A$ | mol $[H^+]/m^3$ | 1.83E-02 |
| Fresh water volume to 1st rinsing tank | $F_1$ | $m^3/s$ | 4.434E-04 |
| Fresh water volume to 2nd rinsing tank | $F_2$ | $m^3/s$ | 2.916E-04 |

| List | Variables | Unit | Value |
|---|---|---|---|
| Fresh water volume to 3rd rinsing tank | $F_3$ | $m^3/s$ | 6.112E-04 |
| Fresh water volume to 4th rinsing tank | $F_4$ | $m^3/s$ | 5.563E-06 |
| Fresh water volume to 5th rinsing tank | $F_5$ | $m^3/s$ | 4.378E-06 |
| Drag out volume | D | $m^3/s$ | 1.393E-06 |
| Cleaning agenttank volume<br>(Alkaline, NaOH) | $V_B$ | $m^3$ | 3.3 |
| Cleaning agenttank volume<br>(Acid, $H_3PO_4$) | $V_A$ | $m^3$ | 9.7 |
| 1st rinsing tank volume | $V_1$ | $m^3$ | 0.86 |
| 2nd rinsing tank volume | $V_2$ | $m^3$ | 1.38 |
| 3rd rinsing tank volume | $V_3$ | $m^3$ | 1.09 |
| 4th rinsing tank volume | $V_4$ | $m^3$ | 0.93 |
| 5th rinsing tank volume | $V_5$ | $m^3$ | 1.34 |
| Lower concentration limit<br>of 2nd rinsing tank | $Z_2^L$ | mol $[OH^-]/m^3$ | 1.995E-07 |
| Upper concentration limit<br>of 2nd rinsing tank | $Z_2^U$ | mol $[OH^-]/m^3$ | 3.981E-07 |
| Lower concentration limit<br>of 5th rinsing tank | $Z_5^L$ | mol $[H^+]/m^3$ | 3.162E-07 |
| Upper concentration limit<br>of 5th rinsing tank | $Z_5^U$ | mol $[H^+]/m^3$ | 3.162E-06 |
| Lower bound of Fresh water flowrate | $F^L$ | $m^3/s$ | 0 |
| Upper bound of Fresh water flowrate | $F^U$ | $m^3/s$ | 1E-02 |

### 5.1.3 Mathematical model of Rinsing process

From real plant conditions, the data have been summarized and obtained the mathematical models which represent the process. The mathematical models illustrate dynamic behaviors of state variables of the process which are of chemical during operation.

The value of variables ($a_n$and $b_n$) from equation 4.1 to 4.18 are be given by best fitting between theoretical curve and plant data. The result of formulating rinsing model is shown as figure 5.6

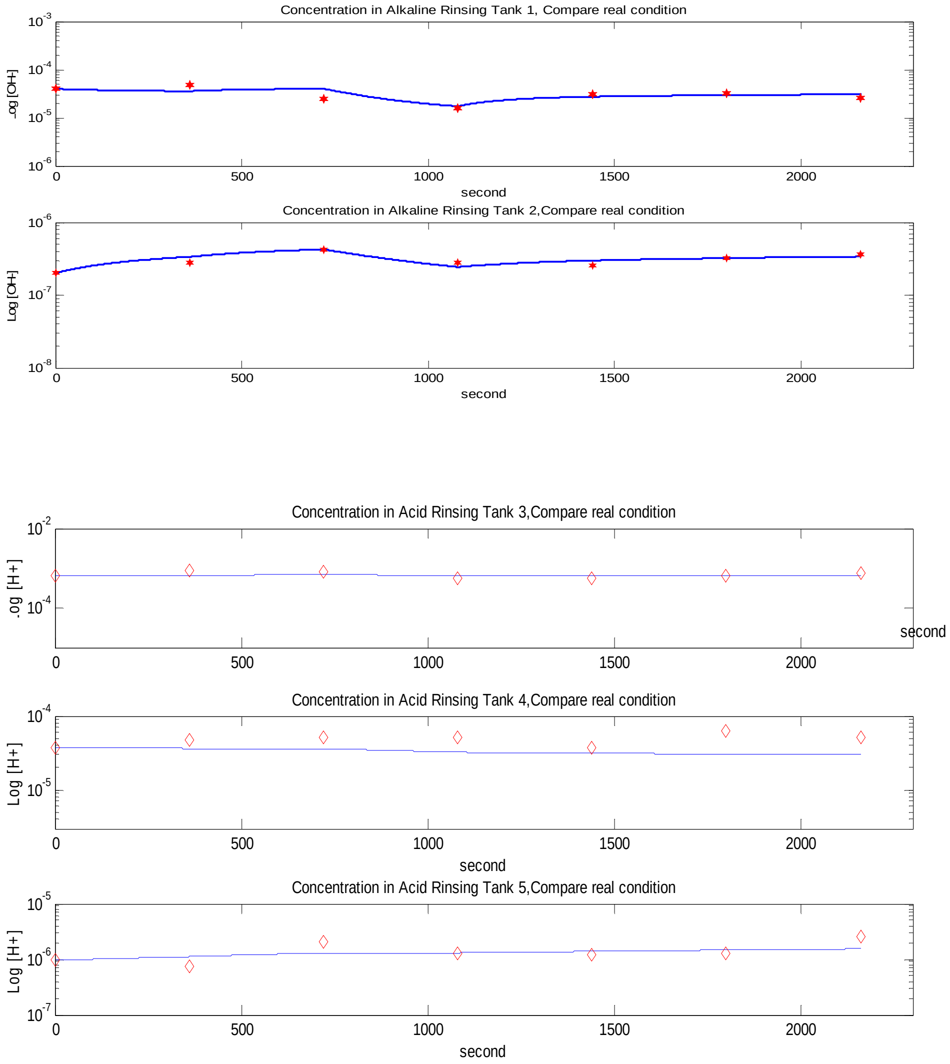

Figure 5.6 Concentration in rinsing stages

The solid line in figure 5.6 which represents the theoretical curve of cleaning agent concentration in rinsing stages after rinsing.

From best fitting between theoretical curve and plant data found that mathematical model can represent to process by tuning drag out volume from 1.393E-06 $m^3/s$ to 2 times (2.786E-06 $m^3/s$)

The imperfect mixing coefficients ($a_n$) are obtained from the best fit of the theoretical curve to the plant data. The values of these coefficients in each rinsing tank are listed in table 5.5

**Table 5.5** Value of the imperfect-mixing coefficients for various rinsing tank.

| **Rinsing stage** | **Imperfect-mixing coefficients** | |
|---|---|---|
| | $a_n$ | $b_n = 1 - a_n$ |
| **Stage-1** | 0.005 | 0.995 |
| **Stage-2** | 0.001 | 0.999 |
| **Stage-3** | 0.001 | 0.999 |
| **Stage-4** | 0.005 | 0.995 |
| **Stage-5** | 0.005 | 0.995 |

The value of the imperfect-mixing coefficient can express the condition of agiation in each rinsing tank which has highest of agiation in the first tank and least of agiation in the third tank (the value is nearly one).

Above the model of rinsing process, we focus on the cleaning agent concentration at the last tank which we normally use to set criterion of discharge water in each tank and fill new fresh water in these tanks. We interest to consider the effects of flowrate of fresh water and drag out volume. Thus we apply this model to find the concentration at the last tank at various of flow rate of fresh (50 to 500 percentage of ordinary value) as shown in figure 5.7-5.11

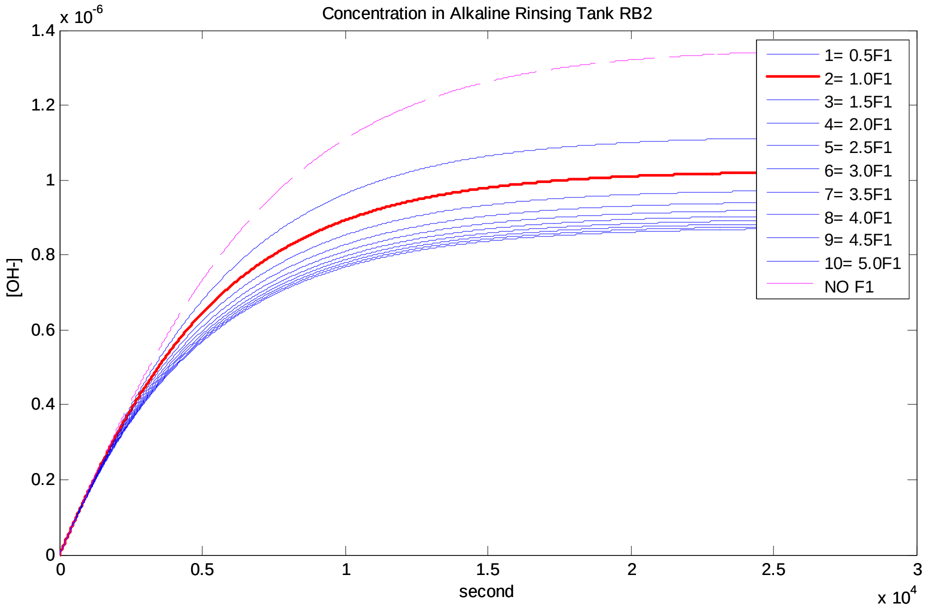

Figure 5.7 Concentration at the 2nd tank at various volume of 1st tank fresh water

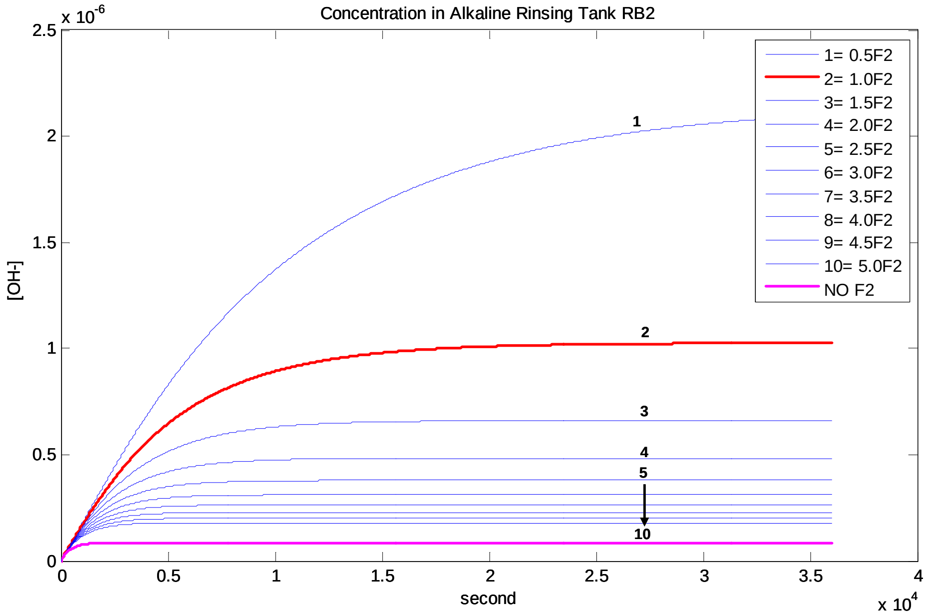

**Figure 5.8** Concentration at the 2nd tank at various volume of 2nd tank fresh water

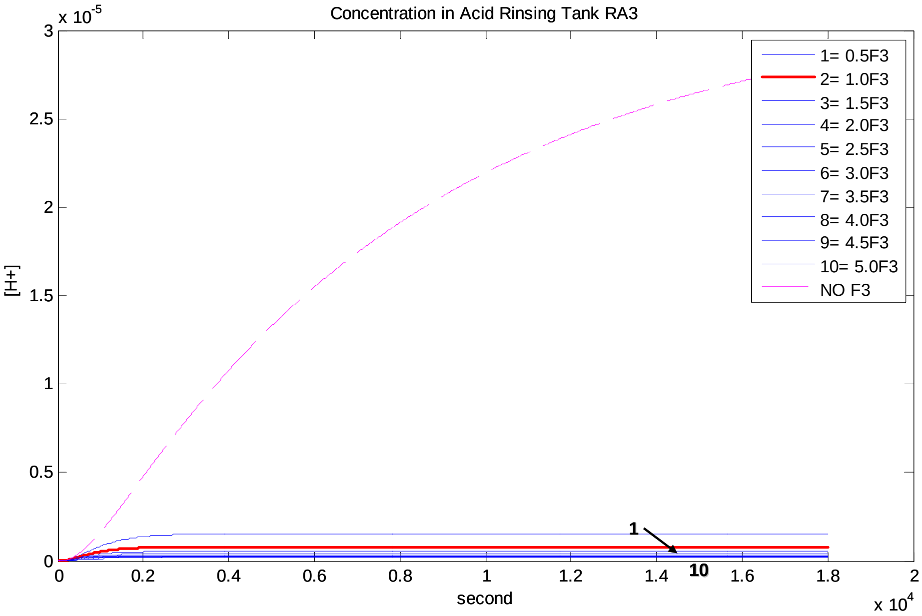

**Figure 5.9** Concentration at the 5th tank at various volume of 3rd tank fresh water

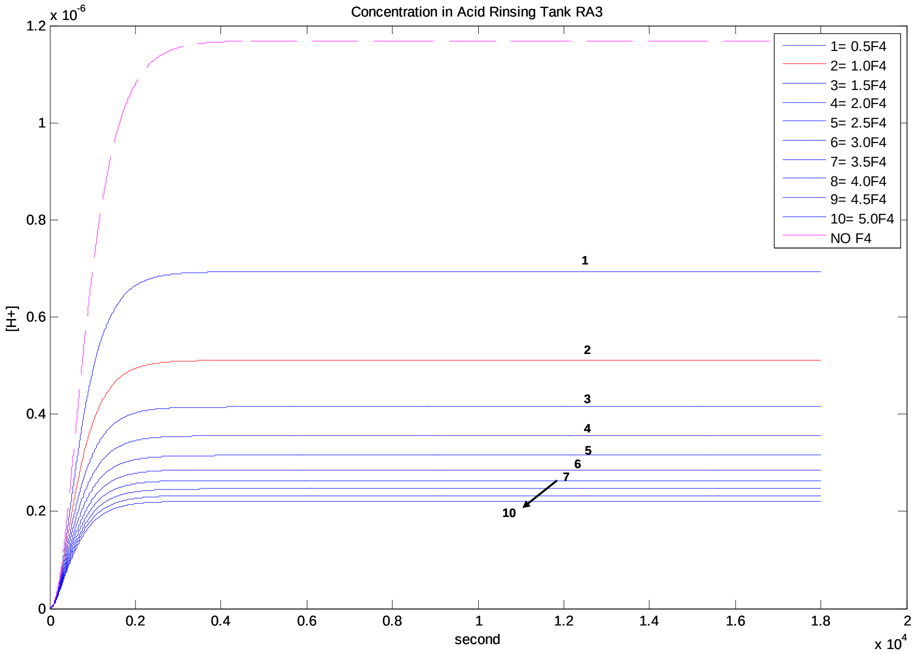

**Figure 5.10** Concentration at the 5th tank at various volume of 4th tank fresh water

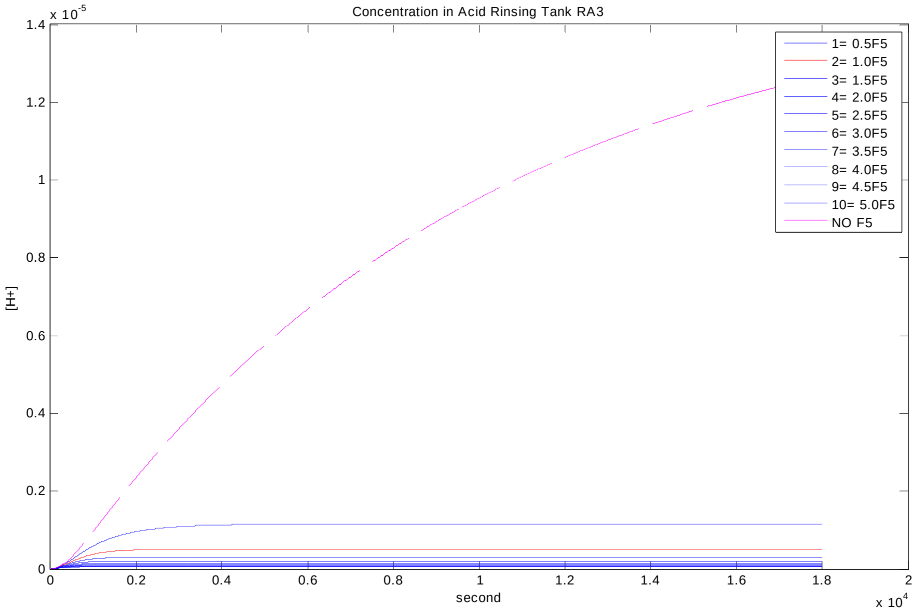

**Figure 5.11** Concentration at the 5th tank at various volume of 5th tank fresh water

From the result of simulation at various volume of fresh water ( 50 to 500 percentage of ordinary value), the concentrations of cleaning agent in the last tank are be listed in table 5.6 to 5.10.

**Table 5.6** Value of the concentration at the last tank for various flowrate of fresh water in 1st tank (F1)

| **Flowrate of F1** | **Concentration at the last alkaline rinsing tank [OH-]** | | |
|---|---|---|---|
| | **$Z_2$** | **pH** | **% Diff** |
| 0 | 1.635E-04 | 10.21 | 15,916.78 |
| 0.5*F1 | 1.113E-06 | 8.05 | 9.01 |
| 1.0*F1 | 1.021E-06 | 8.01 | 0.00 |
| 1.5*F1 | 9.713E-07 | 7.99 | -4.85 |
| 2.0*F1 | 9.404E-07 | 7.97 | -7.87 |
| 2.5*F1 | 9.193E-07 | 7.96 | -9.94 |
| 3.0*F1 | 9.040E-07 | 7.96 | -11.44 |
| 3.5*F1 | 8.923E-07 | 7.95 | -12.58 |
| 4.0*F1 | 8.832E-07 | 7.95 | -13.48 |
| 4.5*F1 | 8.758E-07 | 7.94 | -14.20 |
| 5.0*F1 | 8.697E-07 | 7.94 | -14.80 |

**Table 5.7** Value of the concentration at the last tank for various flowrate of fresh water in 2nd tank (F2)

| **Flowrate of F2** | **Concentration at the last alkaline rinsing tank [OH-]** | | |
|---|---|---|---|
| | **$Z_2$** | **pH** | **% Diff** |
| 0 | 8.607E-08 | 6.93 | -91.61 |
| 0.5*F2 | 2.101E-06 | 8.32 | 104.86 |
| 1.0*F2 | 1.026E-06 | 8.01 | 0.00 |
| 1.5*F2 | 6.612E-07 | 7.82 | -35.54 |
| 2.0*F2 | 4.834E-07 | 7.68 | -52.87 |
| 2.5*F2 | 3.791E-07 | 7.58 | -63.04 |
| 3.0*F2 | 3.110E-07 | 7.49 | -69.68 |
| 3.5*F2 | 2.632E-07 | 7.42 | -74.34 |
| 4.0*F2 | 2.279E-07 | 7.36 | -77.78 |
| 4.5*F2 | 2.008E-07 | 7.30 | -80.43 |
| 5.0*F2 | 1.793E-07 | 7.25 | -82.52 |

**Table 5.8** Value of the concentration at the last tank for various flowrate of fresh water in 3rd tank (F3)

| **Flowrate of F3** | **Concentration at the last Acid rinsing tank [H+]** | | |
|---|---|---|---|
| | **$Z_5$** | **pH** | **% Diff** |
| 0 | 2.813E-05 | 4.55 | 3400.33 |
| 0.5*F3 | 1.539E-06 | 5.81 | 91.48 |
| 1.0*F3 | 8.036E-07 | 6.09 | 0.00 |
| 1.5*F3 | 5.505E-07 | 6.26 | -31.50 |
| 2.0*F3 | 4.224E-07 | 6.37 | -47.44 |
| 2.5*F3 | 3.450E-07 | 6.46 | -57.07 |
| 3.0*F3 | 2.932E-07 | 6.53 | -63.51 |
| 3.5*F3 | 2.561E-07 | 6.59 | -68.13 |
| 4.0*F3 | 2.282E-07 | 6.64 | -71.60 |
| 4.5*F3 | 2.065E-07 | 6.69 | -74.30 |
| 5.0*F3 | 1.891E-07 | 6.72 | -76.47 |

**Table 5.9** Value of the concentration at the last tank for various flowrate of fresh water in 4th tank (F4)

| **Flowrate of F4** | **Concentration at the last Acid rinsing tank [H+]** | | |
|---|---|---|---|
| | **$Z_5$** | **pH** | **% Diff** |
| 0 | 2.813E-05 | 4.55 | 3400.33 |
| 0.5*F4 | 1.539E-06 | 5.81 | 91.48 |
| 1.0*F4 | 8.036E-07 | 6.09 | 0.00 |
| 1.5*F4 | 5.505E-07 | 6.26 | -31.50 |
| 2.0*F4 | 4.224E-07 | 6.37 | -47.44 |
| 2.5*F4 | 3.450E-07 | 6.46 | -57.07 |
| 3.0*F4 | 2.932E-07 | 6.53 | -63.51 |
| 3.5*F4 | 2.561E-07 | 6.59 | -68.13 |
| 4.0*F4 | 2.282E-07 | 6.64 | -71.60 |
| 4.5*F4 | 2.065E-07 | 6.69 | -74.30 |
| 5.0*F4 | 1.891E-07 | 6.72 | -76.47 |

**Table 5.10** Value of the concentration at the last tank for various flowrate of fresh water in 5th tank (F5)

| **Flowrate of F5** | **Concentration at the last Acid rinsing tank [H+]** | | |
|---|---|---|---|
| | **$Z_5$** | **pH** | **% Diff** |
| 0 | 1.267E-05 | 4.90 | 2378.81 |
| 0.5*F5 | 1.156E-06 | 5.94 | 126.23 |
| 1.0*F5 | 5.110E-07 | 6.29 | 0.00 |
| 1.5*F5 | 3.022E-07 | 6.52 | -40.86 |
| 2.0*F5 | 2.043E-07 | 6.69 | -60.01 |
| 2.5*F5 | 1.496E-07 | 6.83 | -70.73 |
| 3.0*F5 | 1.154E-07 | 6.94 | -77.42 |
| 3.5*F5 | 9.246E-08 | 7.03 | -81.91 |
| 4.0*F5 | 7.624E-08 | 7.12 | -85.08 |
| 4.5*F5 | 6.427E-08 | 7.19 | -87.42 |
| 5.0*F5 | 5.517E-08 | 7.26 | -89.20 |

See the simulation result in table 5.3 to 5.7, we can find the relationship between the percentage change of ordinary value (fresh water flowrate) and the percentage change value of concentration in the 2nd and 5th tank as shown in figure 5.12 to 5.16

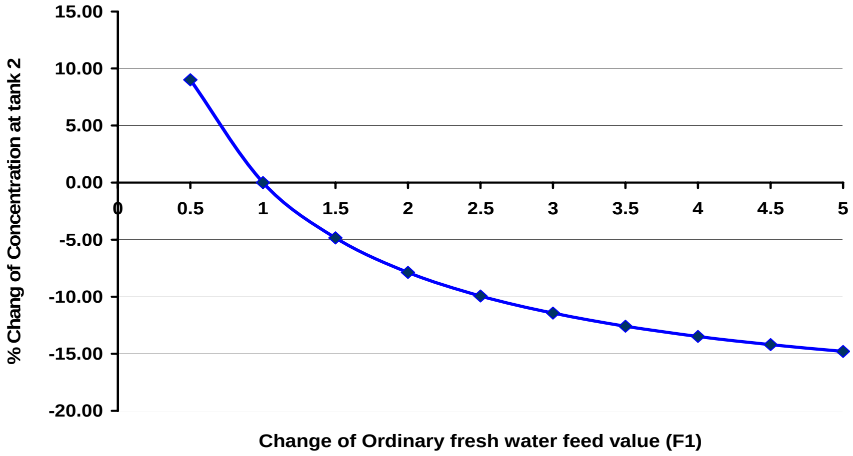

**Figure 5.12** % Change of concentration in last stage ($Z_2$) at various of change of fresh water flowrate F1(times)

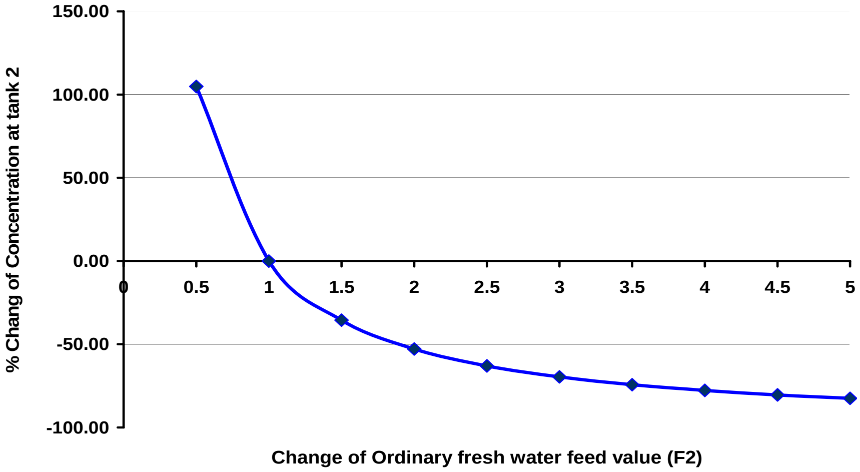

**Figure 5.13** % Change of concentration in last stage ($Z_2$) at various of change of fresh water flowrate F2(times)

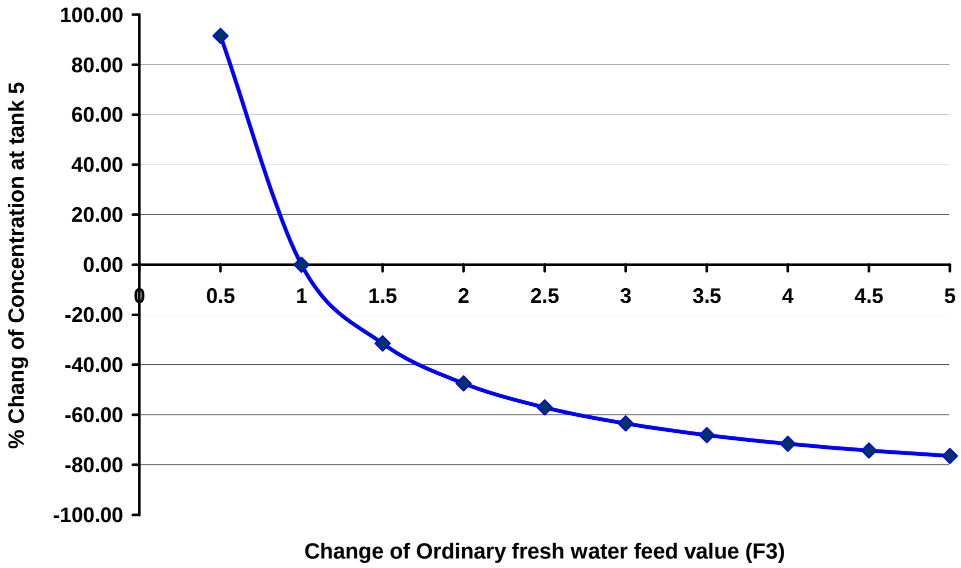

**Figure 5.14** % Cnange of concentration in last stage ($Z_5$) at various of change of fresh water flowrate F3(times)

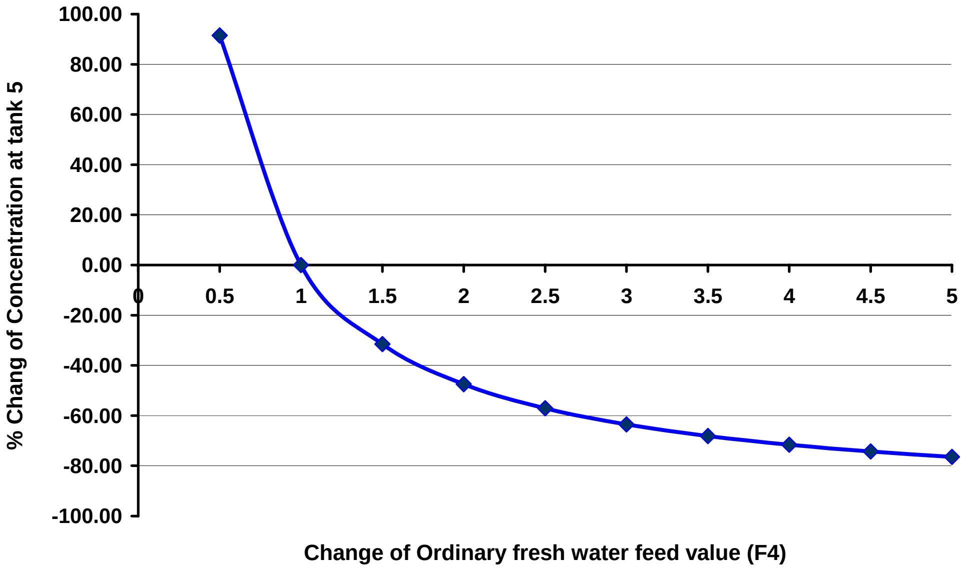

**Figure 5.15** % Change of concentration in last stage ($Z_5$) at various of change of fresh water flowrate F4(times)

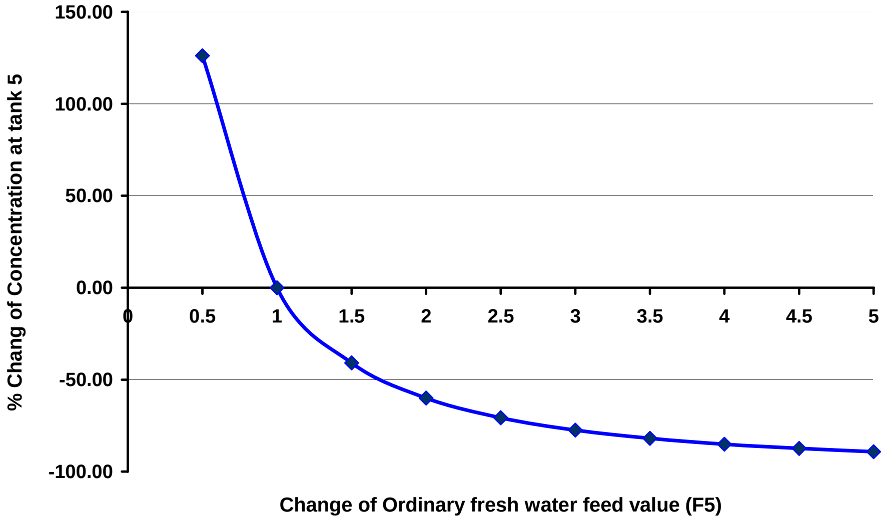

**Figure 5.16** % Change of concentration in last stage ($Z_5$) at various of change of fresh water flowrate F5(times)

From figure 5.12, the relationship between the percentage change value of ordinary water flowrate and the percentage change value of concentration of cleaning agent is linear and the concentration has less change.

figure 5.13-5.16, the relationship between the percentage change value of ordinary water flowrate and the percentage change value of concentration of cleaning agent is nonlinear and the concentration has less change when we increase over 400 percentage of ordinary volume.

In the conclusion, change fresh water flowrate in 2nd and 5th tank has more effect than former tank for the concentration of cleaning agent in the last tank.

## 5.2 Optimization

In this research, we study two cases of optimization the following.

**Case 1 Determine the optimum volume of Fresh water in 2nd tank**

From optimization problem in the section 4.4, and the result form table 5.4 concentration in 2nd tank sensitive to changing of fresh feed flowrate. To determine the optimum volume of fresh water we apply constraint and express the problem as following.

$$\min_{F_1, F_2} \; C_2 = a_2 C_1 + (1 - a_2) Z_2 \tag{5.19}$$

$$\textit{Subject to} \quad V_1 \frac{dZ_1}{dt} = DC_B + F_1 C_F + b_2 R_1 Z_2 - DC_1 - b_1 (F_1 + R_1) Z_1 \tag{5.20}$$

$$V_2 \frac{dZ_2}{dt} = DC_1 + F_2 C_F - DC_2 - b_2 R_1 Z_2 \tag{5.21}$$

$$Z_3 \le Z_3^U \tag{5.22}$$

$$Z_3 = Z_3(t_N) \tag{5.23}$$

When determine the concentration in the last tank at final of cycle time $Z_5 = Z_5(t_N)$, this problem can be solved by using optimization toolbox. The optimization results indicate the dynamic respond of concentration and the optimum volume of fresh water .

The flowrate of fresh water at 1st tank not sensitive to concentration if turn off feed to 1st tank and find the optimum fresh feed flowrate under the same value of allowable concentration in the last tank as shown in table 5.11

**Table 5.**11 Optimum volume of fresh water in Alkaline rinsing stage

| **No.** | **Concentration at the rinsing tank [0H-]** | | | **Flowrate of F1** | **Flowrate of F2** | **Total Flowrate** |
|---|---|---|---|---|---|---|
| | **pH** | **1st** | **2nd** | | | |
| 1 | 8.01 | 6.489E-05 | 1.021E-06 | 4.434E-04 | 2.916E-04 | 7.350E-04 |
| 2 | 8.53 | 7.348E-05 | 3.378E-06 | 5.882E-04 | 5.928E-05 | 6.475E-04 |
| 3 | 8.23 | 9.160E-05 | 1.690E-06 | 3.357E-04 | 1.848E-04 | 5.205E-04 |
| 4 | 8.07 | 7.795E-05 | 1.164E-06 | 3.464E-04 | 2.654E-04 | 6.118E-04 |
| 5 | 8.01 | 7.166E-05 | 1.082E-06 | 3.848E-04 | 2.807E-04 | 6.656E-04 |
| 6 | 7.80 | 7.037E-05 | 6.366E-07 | 1.988E-04 | 4.790E-04 | 6.778E-04 |
| 7 | 7.72 | 5.984E-05 | 5.243E-07 | 2.347E-04 | 5.623E-04 | 7.970E-04 |
| 8 | 7.52 | 4.326E-05 | 3.342E-07 | 2.679E-04 | 8.348E-04 | 1.103E-03 |
| 9 | 7.43 | 3.682E-05 | 2.710E-07 | 2.888E-04 | 1.007E-03 | 1.295E-03 |

From data on table 5.11, the value in No.1 is real condition at factory.The simulation have done on condition decrease feed flowrate to 1st tank and 2nd tank.

In No. 2-6 show optimum fresh floewrate at various acceptable value of concentration which monitor by pH value (pH<8.3)

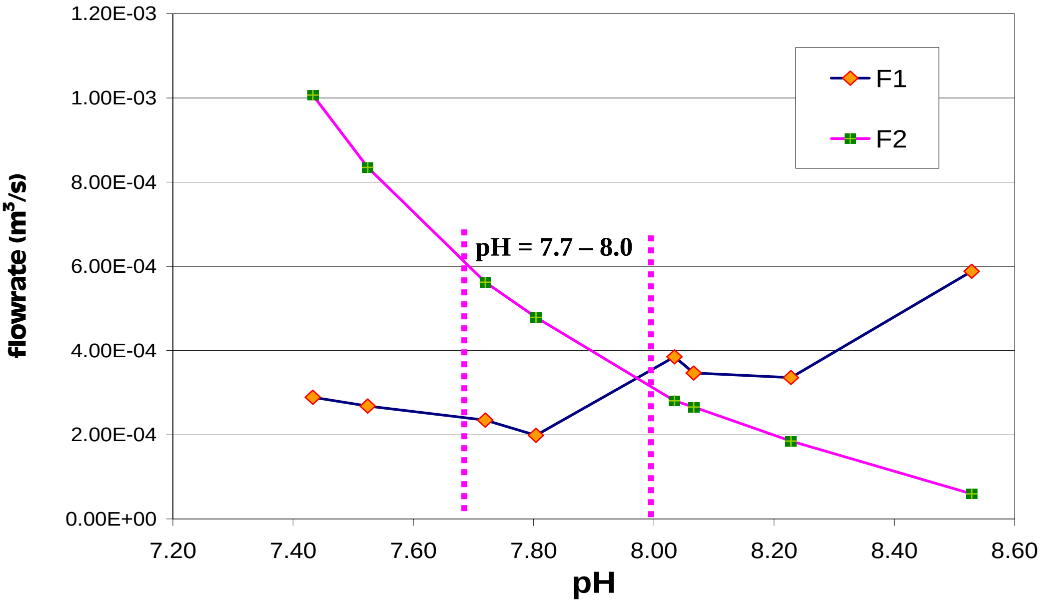

**Figure 5.17** pH change in last stage ($Z_5$) and optimal flowrate

The optimum flowrate of fresh water in $2^{nd}$ tank directly varies with pH desire Considering the optimization result, if the allowance pH is 8.01 as plant condition can save water more 9.5%

**Table 5.12** Summarization and comparison of consumptions between the plant actual method and the offered method with the optimal flowrate

| **Method** | **Flowrate of F1** | **Flowrate of F2** | **Total Flowrate** | **Water saving (%)** | **pH $2^{nd}$ Tank** |
|---|---|---|---|---|---|
| plant actual method | 4.434E-04 | 2.916E-04 | 7.350E-04 | 0 | 8.01 |
| offered method | 3.848E-04 | 2.807E-04 | 6.656E-04 | 9.45 | 8.01 |

### Case 2 Determine the optimum volume of Fresh water in $5^{th}$ tank

From optimization problem in the section 4.4, we apply constraint and express the problem as following.

$$\min_{F_5} C_5 = a_5 C_4 + (1 - a_5) Z_5 \tag{5.24}$$

$$\text{Subject to} \quad V_3 \frac{dZ_3}{dt} = DC_A - DC_3 - b_3 F_3 Z_3 \tag{5.25}$$

$$V_4 \frac{dZ_4}{dt} = DC_3 + b_5 R_2 Z_5 - DC_4 - b_4 (F_4 + R_2) Z_4 \tag{5.26}$$

$$V_5 \frac{dZ_5}{dt} = DC_4 - DC_5 - b_5 R_2 Z_5 \tag{5.27}$$

$$Z_5 \le Z_5^U \tag{5.28}$$

$$Z_5 = Z_5(t_N) \tag{5.29}$$

When determine the cleaning agent concentration in the last tank at final of cycle time $Z_5 = Z_5(t_N)$, this problem can be solved by using optimization toolbox.

The flow rate of fresh water to 5th tank very sensitive to concentration in last tank, Mathematical model optimization have been done to find the optimum fresh feed flowrate under the allowable concentration in the last tank. The optimization results indicate the dynamic respond of concentration and the optimum volume of fresh water as listed in table 5.13.

**Table 5.13** Optimum volume of fresh water in Acid rinsing stage

| **Concentration at the rinsing tank [H+]** | | | | **Flowrate of F3** | **Flowrate of F4** | **Flowrate of F5** | **Total Flowrate** |
|---|---|---|---|---|---|---|---|
| **pH** | **3rd** | **4th** | **5th** | | | | |
| 6.29 | 4.51E-04 | 1.03E-05 | 5.11E-07 | 5.00E-04 | 3.09E-04 | 3.28E-04 | 1.14E-03 |

The optimum flowrate of fresh water in acid stage directly varies with pH desire Considering the optimization result, if the allowance pH is 6.29 as plant condition can save water more 10%

**Table 5.14** Summarization and comparison of consumptions between the plant actual method and the offered method with the optimal flowrate

| **Method** | **Flowrate of F3** | **Flowrate of F4** | **Flowrate of F5** | **Total Flowrate** | **Water saving (%)** | **pH 5th Tank** |
|---|---|---|---|---|---|---|
| plant actual method | 5.56E-04 | 4.38E-04 | 2.70E-04 | 1.26E-03 | 0 | 6.29 |
| offered method | 5.00E-04 | 3.09E-04 | 3.28E-04 | 1.14E-03 | 10.1 | 6.29 |

# CHAPTER VI

# CONCLUSION AND RECOMMENDATIONS

This chapter concludes this thesis and provides a summary of work done during the course of this research. Some recommendations for future work are also given at the final section.

## 6.1 Conclusions

The conclusion of this research can divide in two parts following the research objective

### *6.1.1 Formulation a mathematical model of rinsing process*

The rinsing model in machinery production industry can be provided to describe the dynamic respond of cleaning agent concentration in each rinsing pit at various rinsing time and imperfect mixing condition.

From the simulation result, the change of fresh water feed flowrate in some tank has more sensitivity to the concentration of cleaning agent at the last tank. Especially, in the 1st tank can be decrease flowrate even though concentration in 1st tank will increase but little. The machinery production factory can provide this modal and the result to improve the ordinary rinsing process which it can be decreased the water consumption.

### *6.1.2 Optimization of rinsing model for decreasing water consumption*

The dynamic optimization technique is provided for solving the optimum condition. When acceptable concentration at the last stage are determined, this method can find the optimum flowrate of fresh water feed to each tank

From the experimental result, the change of water flowrate up to acceptable concentration at the last stage which are pH less than 8.3 at 2nd tank and more than 5.5 at 5th tank. To increasing pH at last tank have to increasing flowrate only but in case of decreasing pH can be done by decrease fresh water flowrate at 4th and 5th tank .

At the optimal fresh water flowrate can decrease water usage 9.8% from ordinary water usage or decrease water usage 0.701 $m^3$/hr

**Table 6.1** Summarization and comparison of consumptions between the plant actual method and the offered method with the optimal flowrate

| Method | plant actual method | offered method |
|---|---|---|
| **Flowrate of F1** | 4.43E-04 | 3.85E-04 |
| **Flowrate of F2** | 2.92E-04 | 2.81E-04 |
| **Flowrate of F3** | 5.56E-04 | 5.00E-04 |
| **Flowrate of F4** | 4.38E-04 | 3.09E-04 |
| **Flowrate of F5** | 2.70E-04 | 3.28E-04 |
| **Total Flowrate** | 2.00E-03 | 1.80E-03 |
| **Water saving (%)** | 9.8%<br>(0.701 $m^3$/hr) | |

## 6.2 Recommendations for Future Work

How to develop for further work can divide in two points. First, to study at the current of factory condition, because this research is studying based on simulation of factory condition. Second, to study optimal water reuse network in each stage for more efficiency of water usage.

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# APPENDICES

# APPENDIX A

# EXPERIMENTAL

## Data collection

The example of concentration and fresh water flowrate collected from plant data shown in table A1-A3

**Table A1** Fresh water flowrate at various tank from plant operating data.

| Time | Fresh water flowrate ($m^3/s$) | | | | |
|---|---|---|---|---|---|
| | **F1** | **F2** | **F3** | **F4** | **F5** |
| 10:00 | 4.707E-04 | 2.829E-04 | 6.351E-04 | 5.850E-04 | 4.532E-04 |
| 11:00 | 4.558E-04 | 2.966E-04 | 6.424E-04 | 5.789E-04 | 4.460E-04 |
| 12:00 | 4.445E-04 | 2.883E-04 | 5.376E-04 | 5.412E-04 | 4.230E-04 |
| 13:00 | 4.318E-04 | 3.042E-04 | 6.095E-04 | 5.787E-04 | 4.290E-04 |
| 14:00 | 4.283E-04 | 2.977E-04 | 6.451E-04 | 5.589E-04 | 4.166E-04 |
| 15:00 | 4.376E-04 | 2.917E-04 | 6.185E-04 | 5.084E-04 | 4.877E-04 |
| 16:00 | 4.351E-04 | 2.799E-04 | 5.901E-04 | 5.430E-04 | 4.097E-04 |

**Table A2** Concentration in Alkaline rinsing stage data

| **Time** | **[OH-]** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Alkali** | **1st Tank** | | | | **2nd Tank** | | | |
| | **Day-3** | **Day-1** | **Day-2** | **Day-3** | **AVG.** | **Day-1** | **Day-2** | **Day-3** | **AVG.** |
| 1 | 9.50E-02 | 1.00E-05 | 3.00E-05 | 4.00E-05 | 2.67E-05 | 6.00E-07 | 3.00E-07 | 2.00E-07 | 3.67E-07 |
| 2 | 1.06E-01 | 3.00E-05 | 6.00E-05 | 4.77E-05 | 4.59E-05 | 7.00E-07 | 6.00E-07 | 2.79E-07 | 5.26E-07 |
| 3 | 9.10E-02 | 2.40E-05 | 4.00E-05 | 2.52E-05 | 2.97E-05 | 2.00E-07 | 4.00E-07 | 4.27E-07 | 3.42E-07 |
| 4 | 1.01E-01 | 3.00E-05 | 6.00E-05 | 1.60E-05 | 3.53E-05 | 8.00E-07 | 6.00E-07 | 2.79E-07 | 5.60E-07 |
| 5 | 9.20E-02 | 1.00E-05 | 8.00E-06 | 3.05E-05 | 1.62E-05 | 7.00E-07 | 8.00E-07 | 2.53E-07 | 5.84E-07 |
| 6 | 9.60E-02 | 2.80E-06 | 4.00E-05 | 3.18E-05 | 2.49E-05 | 4.40E-07 | 4.00E-07 | 3.27E-07 | 3.89E-07 |
| 7 | 1.00E-01 | 6.60E-06 | 4.00E-05 | 2.59E-05 | 2.42E-05 | 5.40E-07 | 4.00E-07 | 3.59E-07 | 4.33E-07 |
| **Avg.** | **9.73E-02** | **1.62E-05** | **3.97E-05** | **3.10E-05** | **2.90E-05** | **5.69E-07** | **5.00E-07** | **3.03E-07** | **4.57E-07** |

**Table A3** Concentration in Acid rinsing stage data

| **Time** | **[H+]** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Acid** | **3rd Tank** | | | | **4th tank** | | | | **5th tank** | | | |
| | **Day-3** | **Day-1** | **Day-2** | **Day-3** | **AVG.** | **Day-1** | **Day-2** | **Day-3** | **AVG.** | **Day-1** | **Day-2** | **Day-3** | **AVG.** |
| 1 | 1.84E-02 | 1.15E-03 | 8.41E-04 | 6.41E-04 | 8.77E-04 | 6.00E-05 | 5.92E-05 | 3.79E-05 | 5.24E-05 | 2.00E-06 | 1.26E-06 | 9.53E-07 | 1.40E-06 |
| 2 | 1.83E-02 | 7.50E-04 | 1.00E-03 | 8.47E-04 | 8.66E-04 | 3.00E-05 | 6.68E-04 | 4.68E-05 | 2.48E-04 | 1.00E-06 | 7.24E-07 | 7.42E-07 | 8.22E-07 |
| 3 | 1.89E-02 | 1.01E-03 | 6.00E-04 | 8.06E-04 | 8.05E-04 | 2.70E-05 | 4.12E-05 | 5.12E-05 | 3.98E-05 | 1.20E-06 | 6.41E-07 | 2.04E-06 | 1.29E-06 |
| 4 | 1.87E-02 | 8.50E-04 | 4.55E-04 | 5.55E-04 | 6.20E-04 | 3.00E-05 | 3.32E-04 | 5.12E-05 | 1.38E-04 | 1.00E-06 | 7.65E-07 | 1.28E-06 | 1.02E-06 |
| 5 | 1.82E-02 | 1.00E-03 | 5.55E-04 | 5.40E-04 | 6.98E-04 | 5.00E-05 | 8.19E-04 | 3.79E-05 | 3.02E-04 | 1.00E-06 | 6.41E-07 | 1.20E-06 | 9.47E-07 |
| 6 | 1.81E-02 | 9.50E-04 | 3.41E-04 | 6.41E-04 | 6.44E-04 | 6.00E-05 | 5.71E-04 | 6.41E-05 | 2.32E-04 | 1.90E-06 | 1.79E-06 | 1.28E-06 | 1.66E-06 |
| 7 | 1.86E-02 | 8.00E-04 | 6.24E-04 | 7.24E-04 | 7.16E-04 | 4.00E-05 | 5.82E-04 | 5.12E-05 | 2.24E-04 | 1.50E-06 | 8.98E-07 | 2.56E-06 | 1.65E-06 |
| **Avg.** | **1.85E-02** | **9.30E-04** | **6.31E-04** | **6.79E-04** | **7.47E-04** | **4.24E-05** | **4.39E-04** | **4.86E-05** | **1.77E-04** | **1.37E-06** | **9.60E-07** | **1.44E-06** | **1.26E-06** |

# Mathematic model

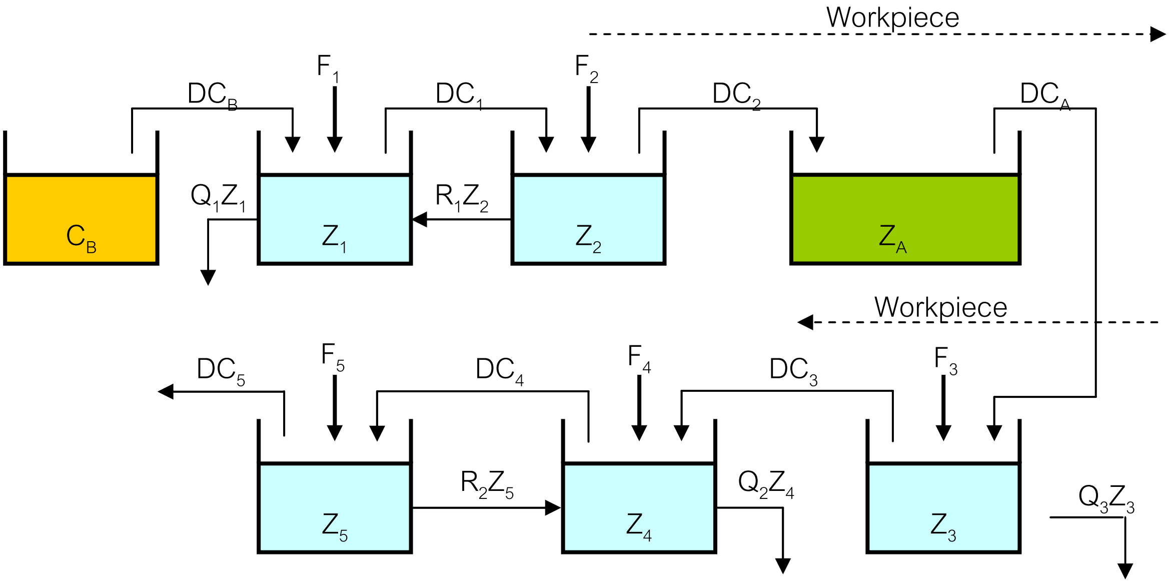


**Figure A1** Rinsing system in this research

Mathematical model, which used to determine concentration of rinse water for each rinser

Assumption based on equal of volume of drag out

$$\frac{dZ_1}{dt} = \frac{DC_B + F_1C_F + b_2R_1Z_2 - DC_1 - b_1(F_1 + R_1)Z_1}{V_1} \qquad (1)$$

$$\frac{dZ_2}{dt} = \frac{DC_1 + F_2C_F - DC_2 - b_2R_1Z_2}{V_2} \qquad (2)$$

$$\frac{dZ_3}{dt} = \frac{DC_A - DC_3 - b_3F_3Z_3}{V_3} \qquad (3)$$

$$\frac{dZ_4}{dt} = \frac{DC_3 + b_5R_2Z_5 - DC_4 - b_4(F_4 + R_2)Z_4}{V_4} \qquad (4)$$

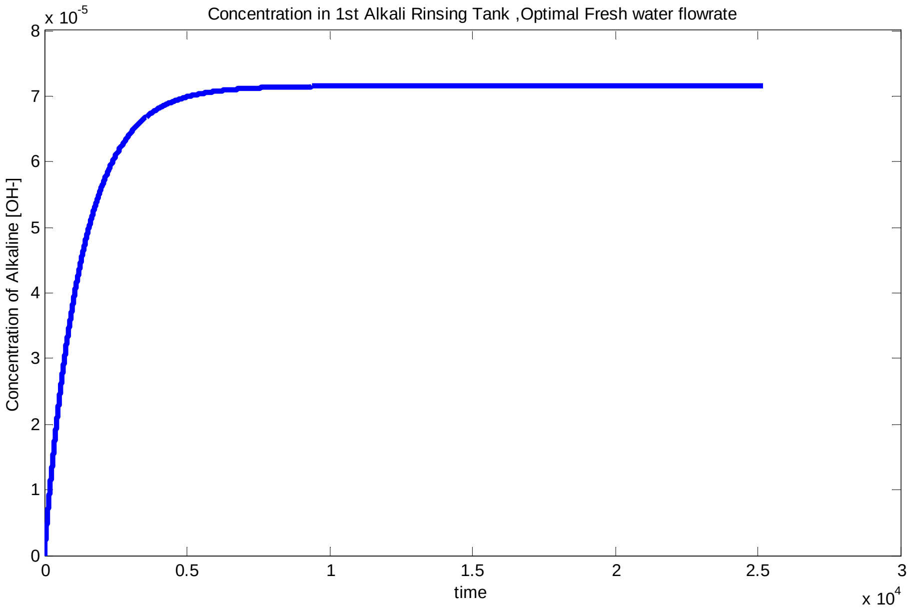
$$\frac{dZ_5}{dt} = \frac{DC_4 - DC_5 - b_5R_2Z_5}{V_5} \qquad (5)$$

Where $C_n = a_n C_{n-1} + b_n Z_n$ $b_n = 1 - a_n$ for n= number of rinser

The coefficient ($a_n$ and $b_n$) can be obtained from fitting curve between model and the experimental point.

## Simulation of Mathematic model with optimum flowrate

The optimum fresh water flowrate, which determined can be shown the dynamics as follow



. **Figure A2** Concentration at 1st tank with optimum fresh water flowrate

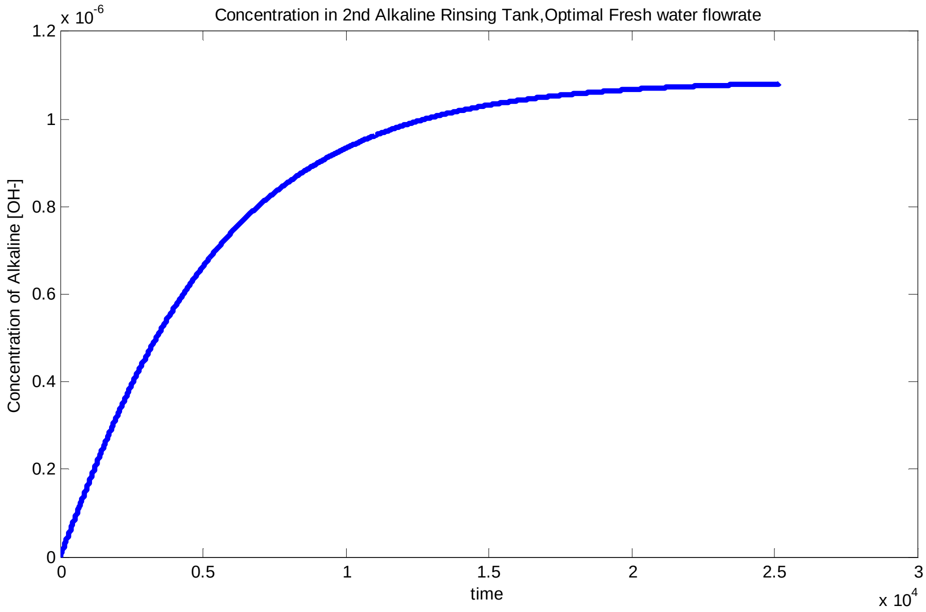


**Figure A3** Concentration at 2$^{nd}$ tank with optimum fresh water flowrate

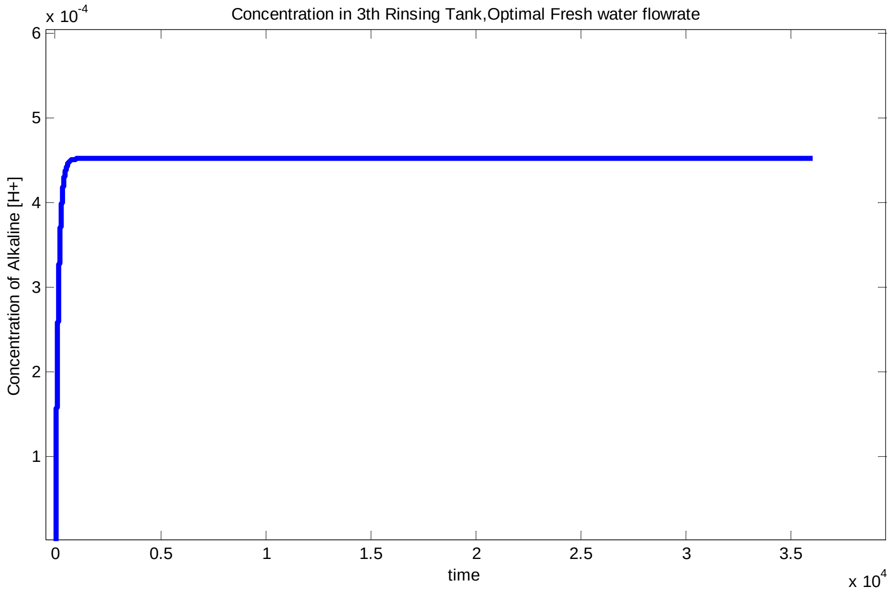


**Figure A4** Concentration at 3$^{rd}$ tank with optimum fresh water flowrate

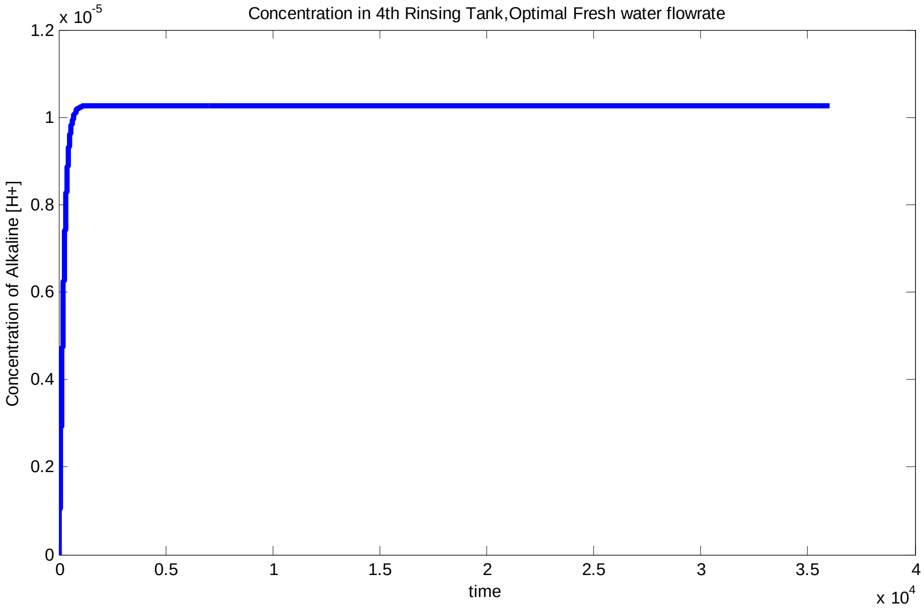


**Figure A5** Concentration at 4th tank with optimum fresh water flowrate

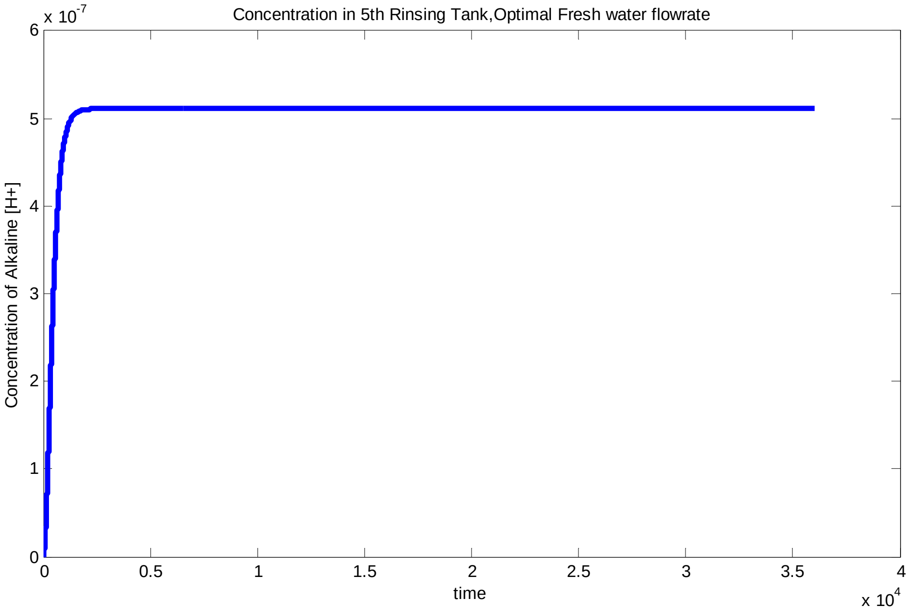


**Figure A6** Concentration at 5th tank with optimum fresh water flowrate

# APPENDIX B

# RINSING TECHNIQUE

This section presents alternatives to traditional rinsing techniques. Two strategies for reducing water use are improving the efficiency of the rinsing operation and controlling the flow of water to the rinsing operations. Contact time and agitation influence the effectiveness of the rinsing operations.

## 1. Improving Rinsing Efficiency

Several methods Used to improve rinsing efficiency. The factors affect to improve efficiency consist contact time and agitation.

### Contact Time

Contact time refers to the length of time workpieces are in the tank. For a given workpiece and tank size, the efficiency of rinsing varies with contact time however production rate varies inversely with contact time. We should do the experiment to find the contact time that satisfies production requirements while providing the highest rinsing efficiency.

### Agitation

Rinsing process that is agitated reduces the required amount of contact time and improve rinsing efficiency. Rinse water can be agitated by pumping either air or water into the rinse tank. Air bubbles create the best turbulence for removing chemical process solution from the workpiece surface. However, misting as the air bubbles break the surface can cause air emissions problems.

We can use many methods to agitate rinse tanks. In manual operation, we lift and lower the workpiece in the rinse tank, creating turbulence. In other tanks, the most effective form of agitation involves a propeller type of agitator, but this method requires extra room to prevent parts from touching the agitator blades. Good agitation also can be obtained with the use of a low-pressure blower. The following is a list of other effective agitation methods:

- Filtered air pumped into the bottom of the tank through a pipe distributor (air sparger).
- Ultrasonic agitation for complex workpieces.
- Mechanical agitation.
- Recirculation of a sidestream from the rinse tank.
- An in-tank pump (a process known as forced water agitation).

**Table B.1** Comparison an advantage between increased contact time and increased agitation.

| **Advantages** | |
|---|---|
| **Increased contact time** | **Increased agitation** |
| ▪ Improves rinsing efficiency.<br>▪ Reduces contamination.<br>▪ If combined with agitation, can shorten contact time. | ▪ Improves rinsing efficiency by removing process chemicals using turbulence (they remain in the tank instead of being dragged out).<br>▪ Reduces water fees, sewer fees, treatment chemical costs, and sludge generation. |

**Table B.2** Comparison a disadvantage between increased contact time and increased agitation.

| Disadvantages | |
|---|---|
| **Increased contact time** | **Increased agitation** |
| ▪ Rinse efficiency varies with contact time<br>▪ Experimentation is needed to find the optimal rinse efficiency<br>▪ Can reduce production rate (this factor varies and the production process should be analyzed to see the effect of this technique on production). | ▪ Manual system requires operators cooperation.<br>▪ Compressed air needs to be contaminant- free otherwise contaminants could enter the water supply and affect work quality (oil- free, low-pressure blowers reduce the likelihood of contamination)<br>▪ Might need an additional tank for water reuse. |

## 2. Controlling Water Flow to Rinses

The following sections present rinsing methods that use less water and increase the efficiency of the rinsing operations.

### Countercurrent Rinsing

Countercurrent rinsing uses sequential rinse tanks in which the water flows in the opposite direction of the work flow (dirtiest to cleanest). Fresh water is added only to the final rinse station and is conveyed, normally by gravity overflow, to the previous rinse tank. Wastewater exits the system from the first rinse tank. Figure B.1 illustrates a three-stage countercurrent rinse system. In some cases, the water contained in the first rinse can be used as makeup water for the process bath. Many factorys with a rinsing process have used this technique successfully to minimize water consumption. The amount of saving water will depend on the number of tanks installed for countercurrent rinsing. In some cases, countercurrent rinsing can achieve 95 percent reductions in rinse flow if the facility uses three rinse tanks; 90 percent is possible with two tanks.

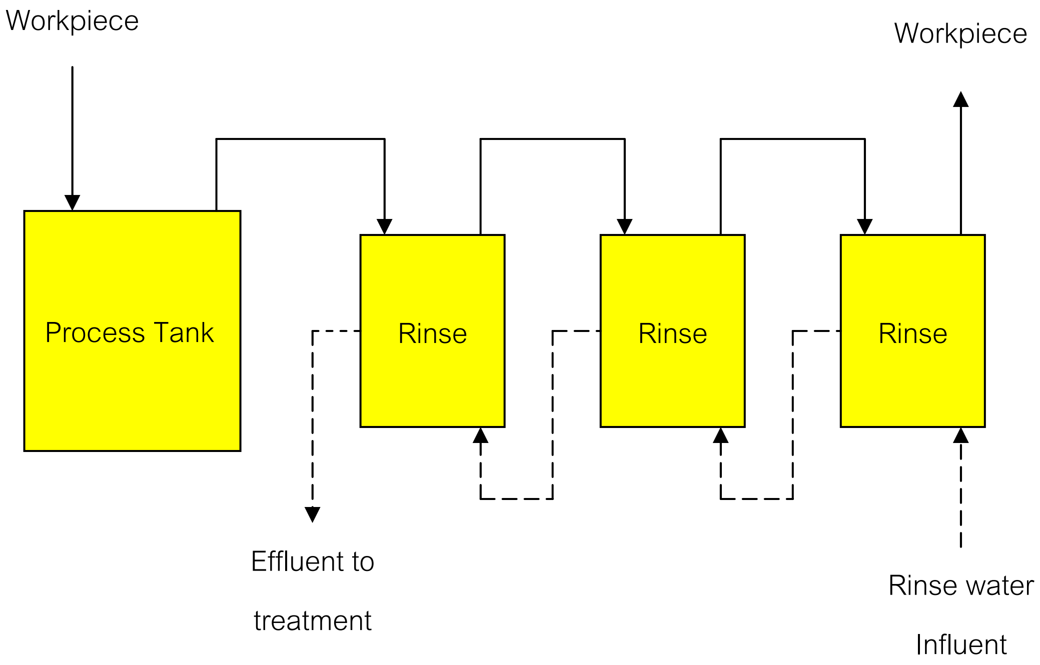


**Figure B.1** Three-Stage Countercurrent Rinsing.

Limitations governing the use of countercurrent rinsing include:

- Factory floor space and/or line space
- Increased cycle time
- General resistance to change

Limited factory floor space can present a significant problem for the improvment. However, careful review of the factory often can reveal opportunities for added rinse stations. The following list presents some of the ways a shop can make room for countercurrent rinsing:

- Reduce the number of process tanks by one or two in order to increase space for rinse tanks.
- Evaluate rinse station sizing. Single station rinses often are sized arbitrarily to match plating tanks. In many cases, platers can install baffles in oversized rinse tanks to create multiple rinse stations.
- Review factory floor layout and seek opportunities to combine processes.
- Extend the line and add rinse stations.

### Static Rinsing (Recovery Rinsing)

If direct countercurrent rinsewater overflow to the process tank is not possible, the first rinse tank after a process bath can be a static rinse that builds up a concentration of dragin. Static rinse tanks with low-temperature processes can be used as pre-dip or post-dip rinses to recover dragout (as much as 80 percent). Periodically, the accumulation in this bath should be concentrated enough for reuse/recycling into the process bath.

### Multistage Static Rinsing

Multistage static rinsing uses multiple dead tanks rather than a system where the water flows from one rinse tank to the other. This process often is used in cadmium plating to keep the metal from entering the waste treatment system. Solution from the first rinse tank can be used to replenish the process bath. However, the solution might need treatment prior to reuse such as filtration to remove contaminants.

**Table B.3** Advantage and disadvantage of multistage static rinsing.

| Advantages | Disadvantages |
|---|---|
| ▪ Increases contact time between the workpiece and rinsewater; improves rinse efficiency.<br>▪ Reduces water use. | ▪ Needs more process steps.<br>▪ Needs additional tanks.<br>▪ Needs more work space.<br>▪ Should use deionized water to reuse rinsewater. |

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### Spray Rinsing

Installation of fixed or movable rinse spray nozzles over the process tank can replace separate rinse tanks. Overspray is returned to the process tank, resulting in reduced dragout. This spray or fog rinsing can be used for either rack or barrel plating.

Spray rinsing uses between 10 to 25 percent less water than dip rinsing. However, this method is not always applicable to metal finishing because the spray rinse might not reach all of the parts of the workpiece. The effectiveness of spray rinsing depends upon part geometry and complexity. Spray rinsing compares favorably with single-dip rinses, but is not as effective as countercurrent rinsing. To address this problem, spray rinsing can be combined with immersion rinsing. In this technique, the workpiece is spray rinsed over the process tank as soon as the part is removed from the process solution. The part then is submerged in an immersion tank. As a result, the spray rinse removes much of the dragout, returning it to the process bath before the workpiece is placed in the dip rinse tank. This allows facilities to use lower water flow rates and reduce dragout.

**Table B.4** Advantage and disadvantage of spay/fog rinsing.

| **Advantages** | **Disadvantages** |
|---|---|
| ▪ Reduces dragout by as much as 75 %.<br>▪ Reduces waste management costs<br>▪ less chemical use and cleaner rinses | ▪ Not be effective in rinsing certain workpieces and might not work in all plating operations. |

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## 3. Rinse Water Reduction

### 3.1 Optimal Rinse Tank Design

The optimal rinse tank design are to attain fast removal of drag-out from the part and complete dispersion of the drag-out throughout the rinse tank. The optimal rinse tank design for different shaped parts, racks and barrels will usually result in the selection of a different combination of design elements.

When parts with various configurations are rinsed in the same tanks, it may be necessary to compromise the design to provide adequate rinsing for all parts.
of the survey respondents. The success rating for this method was 3.82.

### 3.2 Controlling the Flow Rate of Rinsewater Use

Water use reduction can be done by coordinating water use and water use requirements. When these two factors are perfectly matched, the rinse water use for a given work load and tank arrangement is optimized

### 3.3 Flow Restrictors

Flow restrictors are inexpensive devices ,connected in-line with the tanks water inlet piping to regulate the flow of water through the pipe. They are typically an elastomer washer that flexes under pressure such that the higher the water pressure, the smaller the hole available for flow passage.

Therefore, they maintain a relatively constant flow under variable water pressures. Flow restrictors are available in a wide range of sizes.The smaller sized restrictors are used with multiple counterflow rinse tank nd the larger are commonly used with single overflow rinses. The size of a flow restrictor is selected to provide adequate rinsing for all parts.

### 3.4 Manual Control of Water Flow

Manually opening and closing water is obviously dependent on the operator and usually results in inconsistent water use.

Manual control can be improved by installing a main water valve for an entire plating line that stops water flow to all rinse tanks in that line.

### 3.5 Timer Rinse Controls

Timer rinse controls consist of a push-button switch and timer mechanism and a solenoid valve. These units operate in a manner similar to conductivity controllers; the timer controls simply turn water on and off based on a pre-set time period.

In operation the timer setting is selected through trial and error. It is best to select a time period that provides consistently clean rinse water, without excessive waste. Once set, the time period is not changed unless the general trend of production changes.

## 3.6 Flow Meters

These devices do not reduce water use. However, they make the metal finisher aware of water use rates and are useful in identifying the water use.

Flow meters most useful when installed on fresh water feeding individual rinse tanks or, at a minimum, on pipes feeding individual plating lines. Meter readings taken over an extended time period will show trends in water use.

Using these data, can identify specific locations where excessive water use occurs and can correct the problem before long-term wastage has resulted.

# VITA

Soottiwan Noksa-nga was born in Chaiyaphum, Thailand, on February 27, 1981. She graduated high school from Srisaket Wittayalai School, Sisaket province, Thailand. In 1999, she attended Kasetsart University, Bangkok, Thailand where she received the degree of Bachelor of Engineering in Chemical Engineering in 2003. From October 2003 to the end of 2004, she joined to Cleaner Technology internship center, department of engineering Khon Kaen University, Thailand as project engineer and from March 2005 to present, she join The National Metal and Material Technology Center (MTEC), NSTDA as engineer. She entered the Graduate School of Chulalongkorn University to pursue a Master of Engineering in Chemical Engineering and completed in 2008.