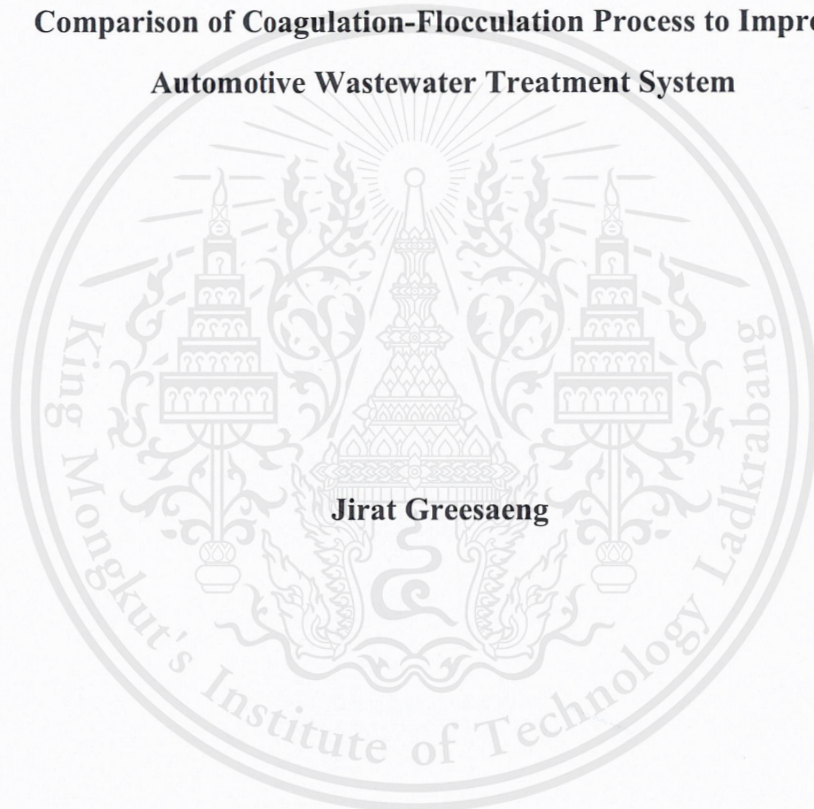




Report of Cooperative Education

Comparison of Coagulation-Flocculation Process to Improve Automotive Wastewater Treatment System



**A Report Submitted in Partial Fulfillment of the Requirements
for the Degree of Bachelor of Engineering (Petrochemical Engineering),
Department of Chemical Engineering, Faculty of Engineering,
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นายจิรัศย์ กริแสง

รายงานนี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิศวกรรมศาสตรบัณฑิต

หลักสูตรวิศวกรรมปีโตรเคมี ภาควิชาวิศวกรรมเคมี คณะวิศวกรรมศาสตร์

สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง

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Cooperative Title: Comparison of Coagulation-Flocculation Process to Improve Automotive Wastewater Treatment System
By: Mr. Jirat Greesaeng
Field of Study: Petrochemical Engineering (B.Eng.)
Advisor: Asst. Prof. Dr. Pornsawan Assawasaengrat
Affiliation: Department of Chemical Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok
Mentor (Position): Mr. Kantapong Lerdwitee (Senior Engineer)
Company: Mitsubishi Motors (Thailand) Co., Ltd.

ABSTRACT

This study was conducted as a treatment process for the automotive wastewater from Mitsubishi Motors (Thailand). According to the local regulations, the automobile industry aimed to provide the high quality of wastewater treatment system. As a result of high levels of cost reduction, it was necessary to find an optimal dosage of coagulant, which was commonly calculated by means of the Jar test. The coagulation-flocculation process was tested to determine the performance of mixed coagulants. Polyaluminum chloride (PAC) was used as coagulant combined with Cationic polyelectrolytes as a coagulant aid. Jar test apparatus was used to conduct this research work. Jar testing was carried out by sampling 500 mL of wastewater from the wastewater treatment plant line 1 and 2. The effects of dosing rate were examined for the reduction of suspended solids (SS), chemical oxygen demand (COD), biological oxygen demand (BOD) and heavy metal level in term of Zinc (Zn). The results of this study showed that the combination of PAC with Cationic polyelectrolyte also called PAC-C. For this combination, the optimum dose of PAC-C was 100 ppm with 2 ppm of Anionic polyacrylamide (APAM) as a flocculant which resulted in effluent SS removal of 92.98% and 88.42%, COD removal of 72.58% and 80.88%, BOD removal of 90.01% and 72.21% and Zn removal of 24.02% and 94.85% for line 1 and 2, respectively. The cost of chemicals and sludge disposal for the treatment of one cubic meter of wastewater was 12.12 Baht/m³. The results of this study were compared with existing chemical treatment system. The comparison implied that the use of coagulant aid could be reduced the total operation cost by 1.22 Baht/m³ which equaled to 9% of the total cost and Carbon dioxide (CO₂) emitted by 35% for comparable removal efficiencies.

Keywords: Automotive wastewater, Cationic polyelectrolyte, Coagulation-flocculation

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Jirat Greesaeng

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NOMENCLATURE

C_i = initial concentration

C_f = final concentration

Q = feed rate of coagulant

V_i = initial volume

V_f = final volume

\dot{V} = flow rate of wastewater



CHAPTER I

INTRODUCTION

1.1 Background

Automobile industries are the common sources of the wastewater in Thailand. These industries especially washing and paint booth sections are the main sources of wastewater discharges. The treatment of paint booth wastewater is challenging due to the potential toxic organic and inorganic micropollutants and high chemical oxygen demand (COD) content. The typical COD of the paint booth wastewater reported in the range of 1,400-5,900 ppm and up to 11,400 ppm, the characteristics are dependent upon the equipment, operational/cleaning processes and the type of chemicals used. It is reported that heavy metals, particularly Chromium (Cr), Zinc (Zn), Nickel (Ni), Lead (Pb), Copper (Cu), Cadmium (Cd), and organic chemicals such as Monocyclic, Polycyclic aromatic hydrocarbons (PAHs) used as solvents and/or additives in paints leading to high COD concentrations [1].

Wastewater discharged from these industries posed a great hazard potential for the environment since it involved many processes, which in turn, could lead to the contamination of freshwater and marine due to various of heavy metals being introduced into the soil and water sources. That is the main problem of most industrial plants. Because of the stringent environmental regulations, industries spent much effort to reduce or treat their wastes in a financially feasible way to achieve permissible discharge levels. It requires sophisticated technology and is costly to maintain. Therefore, there is a search for efficient wastewater treatment methods, but not much investment.

The general concept followed is a combination of a pre-polymerized coagulant and a cationic polyelectrolyte into one reagent is thought to improve the treatment efficiency and the overall cost-effectiveness. Therefore, the coagulation-flocculation process was performed to find out the performance of coagulants using Polyaluminum chloride (PAC) and cationic polyelectrolyte in combinations form which is also called PAC-C [2].

This study focuses on physicochemical treatability of paint booth waste streams combined with a domestic wastewater of Mitsubishi Motors (Thailand) that automobile production factory located in Laem Chabang Industrial Estate. The effectiveness of PAC-C coagulant was examined. That coagulant is aided by Anionic polyacrylamide (APAM) as a flocculant to treat automotive wastewater in terms of suspended solids (SS), COD, biological oxygen demand (BOD) and heavy metals (Zn) removal. The current coagulant used in the plant is based on Ferric chloride (FeCl_3) solution that is acidic coagulant. In the coagulation of heavy metals in wastewater the pH should be alkaline, so it results in the wasteful of the Calcium hydroxide ($\text{Ca}(\text{OH})_2$) used to adjust the pH. The amount of floc is direct variation with FeCl_3 and $\text{Ca}(\text{OH})_2$ volume, thus that will generate large amounts of sludge from the treating process as well. Therefore, the PAC-C coagulants have been investigated to improve coagulation efficiency.

1.2 Objectives

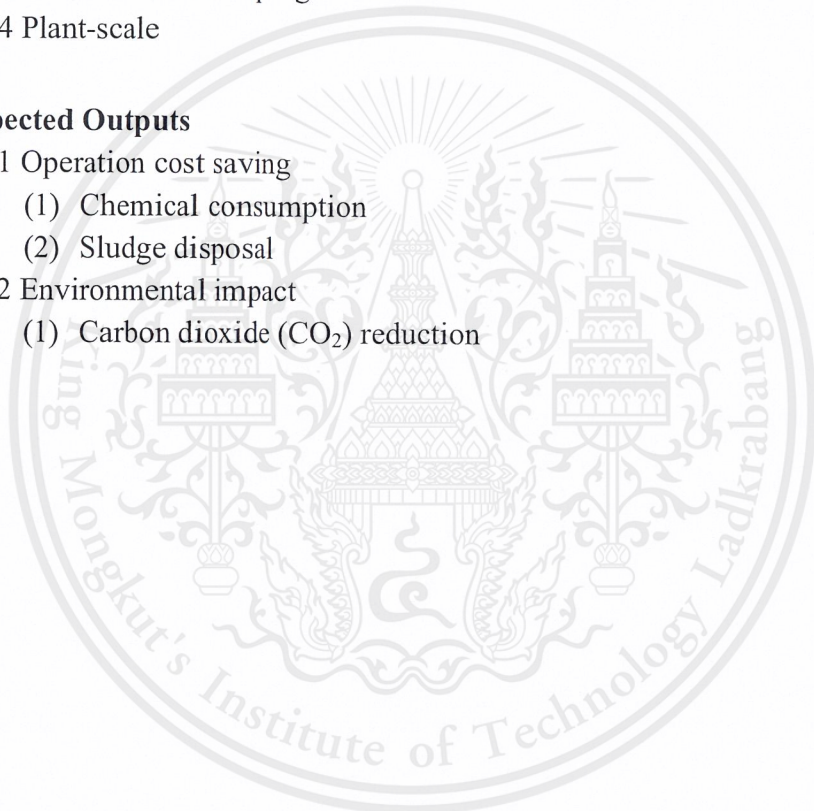
- 1.2.1 To study jar testing and coagulation-flocculation process
- 1.2.2 To improve automotive wastewater treatment system
- 1.2.3 To reduce the operation cost
- 1.2.4 To reduce the environmental impact
- 1.2.5 To treat the wastewater from the production process to reach the standard quality of Industrial Estate Authority of Thailand (IEAT).

1.3 Scopes of Work

- 1.3.1 Study on coagulation-flocculation of PAC-C coagulant at different dosage
- 1.3.2 Plant-scale trial with PAC-C coagulant at optimal dosage
- 1.3.3 Comparison of the parameters analysis results of effluent between existing and new chemical treatment program
- 1.3.4 Plant-scale

1.4 Expected Outputs

- 1.4.1 Operation cost saving
 - (1) Chemical consumption
 - (2) Sludge disposal
- 1.4.2 Environmental impact
 - (1) Carbon dioxide (CO₂) reduction



CHAPTER II

LITERATURE REVIEW

2.1 Terms and Definitions [3]

Ideally, this section should commence with widely accepted definitions of coagulation and flocculation so as not to perpetuate confusion. However, when the abundant literature on the subject is consulted it becomes evident that a number of definitions have been variously adopted. Furthermore, it appears that at times, the terms coagulation and flocculation have been used interchangeably. It is apparent that some of the confusion has been caused by the water treatment industry itself, which has used all manner of definitions of its own.

In an attempt to avoid ambiguity, and to follow generally accepted definitions, this thesis adopts the following definitions:

- Coagulation is the process whereby destabilization of a given suspension or solution is affected. That is, the function of coagulation is to overcome the factors that promote the stability of a given system.
- Flocculation is the process whereby destabilized particles, or particles formed as a result of destabilization, are induced to come together, make contact, and thereby form large(r) agglomerates.
- Coagulant refers to the chemical or substance added to a given suspension or solution to effect destabilization.
- Flocculant (or filter) is the chemicals or substances added to a destabilized suspension or solution to accelerate the rate of flocculation, or to strengthen flocs formed during flocculation.

Hence, in the case of a metal coagulant (for example, aluminum sulphate or ferric chloride) added to, say, a clay suspension, the metal coagulant is being employed as a primary coagulant. If a cationic polyelectrolyte were to be added in place of the metal coagulant, then one would refer to the polyelectrolyte as the primary coagulant. In both cases, the primary coagulant is added to destabilize the clay dispersion. If, in the case of metal coagulant addition to the clay suspension, an anionic polyelectrolyte, say, was subsequently added, the polyelectrolyte would be employed as a flocculant.

2.2 Coagulation-Flocculation Process

Coagulation-flocculation is used widely during water or wastewater treatment. It is an integral treatment step in the surface or underground waters treatment, intended for human consumption. Typical applications are the removal/separation of colloids and suspended particles, of natural organic matter, or of metal ions. In wastewater treatment, additional applications include the removal of toxic metals, anions (i.e. phosphates), color, odor etc. [4,14].

Small particles, which are called colloidal suspension. In general, particle sizes are in the range of 10^{-6} to 10^{-3} mm. (Figure 2.1). Due to its very small size, it cannot be precipitated with its own weight for a limited time. The only way for settling and the subsequent separation is to come closer, to make contacts and to form larger particles, which can be settled easier. In addition, when the colloidal particles are in the water, they have a uniform charge. Hydrophilic is a positive charge, such as organic matter, soap or detergent. Hydrophobic is usually negatively charged, such as clay particles. Since the particles have a charge, the particles with the same charge have the electrostatic repulsive forces constrain the particles from approaching each other and the suspension is characterized as stable. Therefore, a long time period is required for settling. To make the particles coalesce and clump together, the whole treatment process of coagulation-flocculation can be divided into two distinct procedures [3,4].

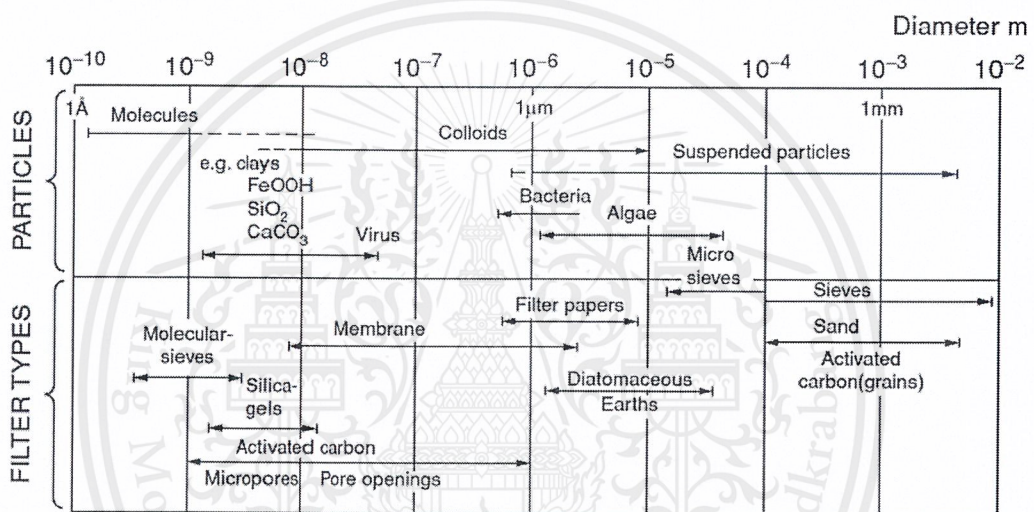


Figure 2.1 Size spectrum of waterborne particles and filter pores [3]

2.1.1 Stability and destabilization

The first one termed coagulation, is the process whereby destabilization of a given colloidal suspension or solution is taking place. The function of coagulation is to overcome the factors that promote the stability of a given system. It is achieved with the use of appropriate chemicals, usually aluminum or iron salts, the so-called coagulant agents. Destabilization of colloidal suspension by one of the following mechanisms:

(1) Thickness reduction mechanism (Diffuse layer) by adding the opposite charge ion to the colloid suspension in the diffusion layer. This will cause the zeta potential at the outermost surface of the water to decrease (Figure 2.2). Destabilization by reducing the thickness of the diffusion layer with the addition of various salts has the following interesting points: The amount of electrical conductivity containing cationic ions added to destroy colloidal stability by the method of reducing the thickness of the diffusion layer does not depend on the concentration of the colloid. No matter how many positive ions are added, it will not be possible for the colloid to change its charge from negative to positive (Charge reversal).

Colloids and interfaces

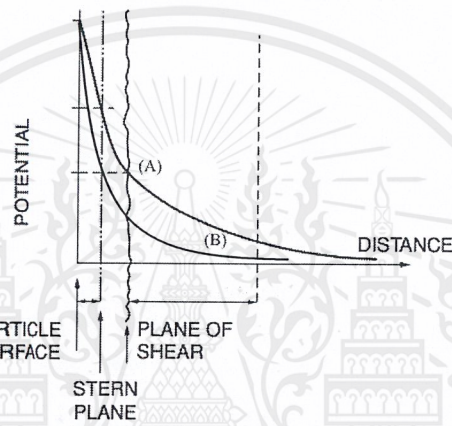
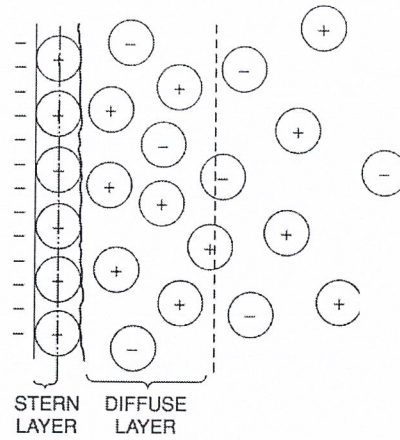


Figure 2.2 The effect of ion addition on the colloid: (A) before addition of ion; (B) after the addition of ions. [3]

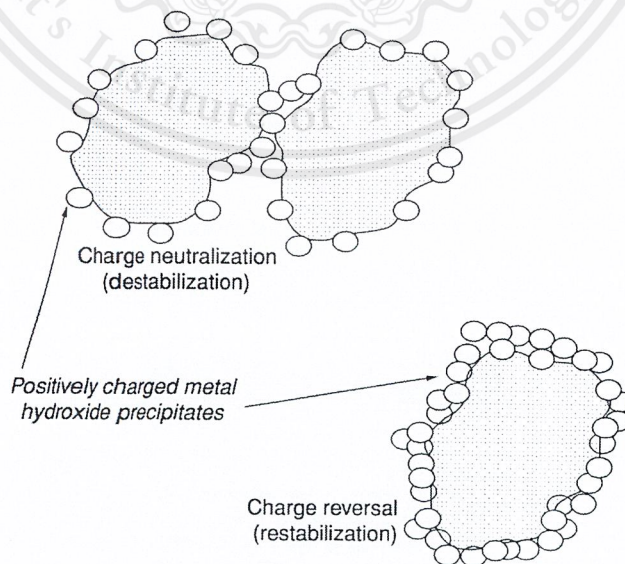


Figure 2.3 Possible schematic of metal hydroxide-particle interaction [3]

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(2) Adsorption and charge neutralization of the colloidal particles by the addition of some coagulant containing the functional group that has the potential to reverse charge the colloidal particles and adsorb the surface. This will result in the reduction of the colloidal electrical potential, which in turn destabilizes itself. It creates the opportunity to contact the other particles so they are large and can be precipitated by their weight. This mechanism has a narrow suitability range which controls the performance of the work is difficult because the coagulant must be justified. If it is too low, the coagulation will not occur, but if it is too high, the functional group will adsorb to the particle surface, causing the particles to become positive and stable (Figure 2.3).

(3) The crystalline mechanism for the colloidal suspension which is also called (Sweep coagulation). This is different from the first two mechanisms. The appropriate coagulant (Optimum dosage) content was inversely correlated with colloidal concentration. In the case of low turbidity water, more coagulants are required in coagulation. In contrast, high turbidity water may be less coagulant. The reason is that low turbidity water has less chance of contact between the particles. Even the destabilization of colloid is present, coagulation may not be as good as it should be. The use of high coagulant is used to produce large amounts of crystals as a target for colloidal particles. In case of high turbidity, the chance of contact is very high, so it is not necessary to rely on the external contact as much as the first case. For example, the alum ($\text{Al}(\text{OH})_3$) is used to make the particles come closer to form the floc.

(4) Bridge mechanism connects colloidal particles using a large polymer molecule, when added to water, gives a large amount of ions to trap the colloidal particles and also attaches to other colloidal particle to form the floc.



Figure 2.4 Stages in the bridging mechanism: (i) Dispersion; (ii) Adsorption; (iii) Compression or settling down; (iv) Collision [3]

The flocs produced from the bridging mechanism are stronger than those formed from particles destabilization by simple metal salt coagulants. Therefore, aggregates formed by polyelectrolytes are more resistant to breakage via hydrodynamic stress.

2.1.2 Agglomeration

The second sub-process, termed flocculation, refers to the induction of destabilized particles in order to come together, to make contact and thereby, to form large agglomerates, which can be separated easier usually through gravity settling. There are several ways to agglomeration by the following [12]:

(1) The colloidal particles move in water until the formation of the contact occurs. This practice is most commonly used to stir the water in such a way that different parts of the water have different flow rates, causing particles to move at different speeds, resulting in increased contact, in which particle aggregation is brought about by inducing velocity gradients and mixing in the suspension. Movement of water must not be too fast, otherwise, the floc may break or fall apart. This is a method commonly used. The device to create contact or create a flocculation called slow stirred tank and how to create this contact is called macro-flocculation (orthokinetic flocculation). Colloidal particles with this flocculation should be larger than 0.1-1 micron and have a concentration of not less than 50 mg/L.

(2) The contact of colloidal particles can occur by relying on the Brownian motion which particles aggregation is brought about by the thermal motion of fluid molecules. It can be said that Brownian motion is called micro-flocculation (perikinetic flocculation).

(3) Particle contact occurs due to the deposition of an unequal velocity of particles. Flocculation in this way occurs simultaneously with sedimentation, which results in the removal of colloidal particles out of the water. This type of flocculation has a particle size greater than 5 microns and a concentration of not less than 50 mg/L. In practice, particles of this magnitude can be early flocculated, when it comes to sedimentation, flocculation occurs again during sedimentation.

(4) In cases where colloidal particles are larger than 0.1-1 microns but smaller than 5 microns and have a concentration of less than 50 mg/L. Flocculation may occur by creating an orthogonal flocculation, but may occur slowly due to the low chance of contact. The solution may be: use a quick filter or 2-layer filter, the filter helps increase the rate of contact and also forces the particles to move together. The use of this filter is called contact filtration. However, since the space in the filter layer is limited. This method is suitable for particles with a concentration of not more than 50 mg/L. Using sandy gravel instead of sand can increase the volume of the gap, but reduces the contact surface area. Therefore, it may result in flocculation as bad as the sand layer.

(5) In cases where colloidal particles are larger than 3 microns but low concentrations, contact formation may be used as a filter, but the filter used should be larger than sand.

2.3 Coagulation Reagents

The commonly used metal coagulant fall into two general categories: those based on aluminum and those based on iron. This project deals with the aluminum-based coagulants, hence this will be described further.

The application of simple metal coagulants (conventional) is widespread, especially due to the relatively low cost and the simpler application route. However, they exhibit several disadvantages, such as the need for pH adjustment before or after treatment, the sensitivity to temperature changes, the need for higher dosages because the charge neutralization is not usually sufficient, the sensitivity to sample specific characteristics and composition, as well as the excess sludge production.

2.2.1 Pre-polymerized coagulants [4]

Several research efforts have been devoted to improve the efficiency of coagulation-flocculation process, the way for improvement seemed to be their (partial) polymerization. The result of these efforts was the production of a range of pre-polymerized aluminum solutions, referred as Polyaluminum chlorides (PAC), Polyaluminum sulfates (PAS), or Polyaluminum chloro-sulfates (PACS), with variable degrees of polymerization. These products and especially the first one (PAC) are used extensively worldwide during the last decades, with an ever increasing demand. Their properties were intensively examined and have proved to be more efficient in lower dosages, in wider pH, temperature and colloids concentration ranges, than the conventional simpler ones, leading to cost and operative more effective treatment

Their superiority is related to the different aluminum species distribution in the polymerized, as compared with the non-polymerized solutions. Aluminum exists in water solutions and at pH values < 3 as six-coordinated Al^{3+} ion. With increase of pH value, the aluminum ion begins to hydrolyze, and various products can be formed. The hydrolyzation of Al ion is extremely complicated, involving hydrolysis and polymerization reactions, thus leading apart from various monomeric, also to several polymeric species formations [5]. With conventional coagulants, these reactions are entirely uncontrolled, and the coagulation efficiency is based more to $Al(OH)_3$ formation (around the pH 6.5-7) and less to charge neutralization, as the hydrolysis reactions are proceeding fast and hence, the concentration of positively charged Al ions is restricted. In the case of PAC, the pre-polymerization aims to control up to a certain extent the aforementioned reactions. With the partial neutralization of Al solution by adding a base solution and then by aging, these reactions may take place at some extent and various Al species can be formed. The most important reaction is supposed to be that leading to $Al(OH)^-$ formation. This aluminum anionic form is claimed to be the precursor for the polymeric Al_{13} creation. $Al_{13}(AlO_4Al_{12}(OH)_{24}(H_2O)_{12}^{6+,7+})$ with ϵ -Keggin structure is one of many possible PAC polymeric compounds, like dimmers (e.g. $Al_{22}(OH)^{4+}$), trimers (e.g. $Al_{34}(OH)^{5+}$) among several others, even larger than Al_{13} i.e. with more than 13 aluminum atoms (e.g. $Al_{30}O_8(OH)_{56}(H_2O)_{24}^{18+}$), which transform continuously from one form to another. However, Al_{13} is claimed to be the most stable aluminum specie in a partially neutralized aluminum solution and the improved coagulation properties of PAC are thought to be due to its existence, i.e. increased

charge neutralization capability (coagulation) and increased molecular size and aggregation ability (flocculation). Further on, the decrease of monomeric Al in favor of Al_{13} and of the other polymeric compounds eliminates the hydrolysis reactions and therefore, results in a minor impact of pH value after treatment. The production of pre-polymerized coagulants involves the partial neutralization of an Al solution with a base solution. Many parameters can affect the properties of the final product, i.e. the base addition rate, the stirring speed, the synthesis temperature, the presence of other anions (e.g. Cl^- , SO_4^{2-} , CO_3^{2-}), the aging time etc. The most important parameters however, is claimed to be the molar ratio of bound hydroxide to the concentration of metal cations (i.e. the OH/Al molar ratio). It is referred as basicity and is also used to describe conveniently the polymerization degree of coagulant agents.

2.4 Polyelectrolytes

In water treatment parlance, the term “polyelectrolytes” referred to a category of macromolecules that are classified, as cationic, anionic or nonionic. The classification is based on the electric charge that is present on the hydrolysis products of the macromolecule. Cationic polymers are frequently used as primary coagulants while anionic and nonionic polymers are used as coagulant aid [6,12]. The fundamental operational mechanism of the polyelectrolytes, either as the primary coagulant or coagulant aid, occurs via destabilization of dissolved or particulate matters by bridging mechanism. Bridging mechanism occurs when segments of the polymer chain adsorb on more than one dissolved or particulate matters, thereby linking them together to form an easily settleable macro flocs (Figure 2.4) [5,12,13]. That the flocs produced from the bridging mechanism are stronger than those formed from particles destabilization by simple metal salt coagulants [6,7,8]. Therefore, aggregates formed by polyelectrolytes are more resistant to breakage via hydrodynamic stress [8]. An overview of the role of polyelectrolytes in coagulation-flocculation operation showed that they enhance floc settling rate, improve process economy, enhances the product water quality, and produced sludge with improved quality characteristics [7,9,10]. An overview of the genus of polyelectrolytes, as enunciated by Tripathy and Ranjan De (2006) and Bolto and Gregory (2007), is presented below:

2.3.1 Cationic polyelectrolytes

Cationic polyelectrolytes derived their properties from the density and distribution of positive charges along the skeletal framework and the chain conformation and solubility depend on the degree of hydrolysis in aqua medium. Oftentimes, these macromolecules possess quaternary ammonium groups, with formal positive charge, irrespective of the pH value of the aqueous phase [11]. They are usually referred to as strong electrolyte polymers and examples include Polydiallyldimethyl ammonium chloride, Cationic polyacrylamides etc. [6]. Aside the strong electrolyte polymers, weak electrolyte polymers that acquire cationic properties in acidic pH range have also been listed by [5]. Tripathy and Ranjan De (2006) have also delineated water-soluble polymers, containing cationic charge, into three categories thus: ammonium (including amines), sulfonium and phosphonium quaternaries [20].

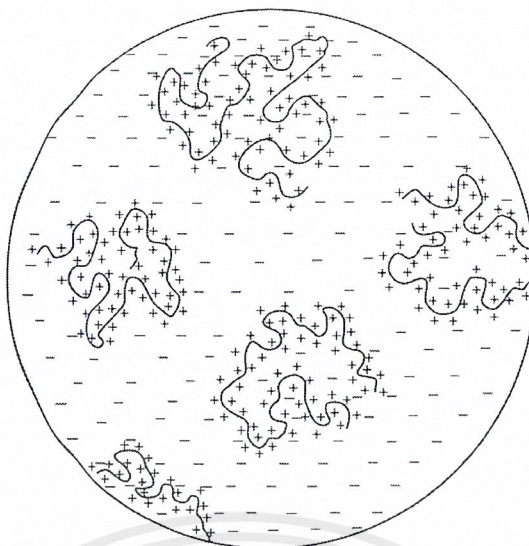


Figure 2.5 Possible arrangement of adsorbed polycations on a particle [3]

2.3.2 Anionic polyelectrolytes

An overview of the chemistry of polyelectrolytes that are anionic in nature showed that the values of the monomer units that contribute to the charge and molecular weights are in the range of 1–100%. Several types of anionic functional groups have been identified in anionic polyelectrolytes but the commonly observed species in commercial anionic polyelectrolytes is the carboxylate group [11]. The largest anionic commercial polyelectrolytes include homopoly (acrylic acid), poly (acrylic acid-co-acrylamide) and hydrolyzed polyacrylamide, while hydrolyzed polyacrylonitrile constitute the minor group [11]. Consequent upon the fact that the sulfonic functional group is stronger acid than the carboxyl group, polymers that contains sulfonic acid functional groups are also readily used as anionic polyelectrolytes. Examples of the polymers containing sulfonic acid groups are poly (vinyl sulfonic acid) (PVSA) and poly (styrene sulfonic acid) (PSSA) [11].

2.3.3 Nonionic polymers

In coagulation-flocculation operations, the polymer is termed “nonionic polyelectrolyte” on the caveat that less than 1% of the monomeric unit is ionisable [11]. The operation of these types of polymers, occur primarily by bridging mechanism. Thus, for this genre of polymers to function effectively, the molecular weight must be high or very high [11]. The commonest member of this species of polyelectrolytes is poly-acrylamide, followed by poly (ethylene oxide) [11].

In recent years, the relevant research in the coagulation-flocculation field has focused mainly on understanding the behaviour and aquatic chemistry of pre-polymerized coagulants, such as polyaluminum chloride, and to the further improvement of their properties. The main reason for the higher efficiency of organic polymers is their higher molecular weight (MW), which implies better flocculation

properties. Thus, the increase of molecular weight and size of the pre-polymerized coagulants is thought to be the way for further improvement [16,17].

The general concept followed is, the introduction of various additives in the structure of a pre-polymerized coagulant, in order to produce a homogenous, stable product with higher MW and improved coagulation-flocculation performance, than the initial reagent. The challenge to confront is the desirable combination of higher efficiency and cost-effectiveness, which are the basic prerequisites for the development of new products [16,18].



CHAPTER III RESEARCH METHODOLOGY

3.1 Description of Site

The project study was conducted in a wastewater treatment plant in Laem Chabang Industrial Estate, Thailand. That is owned by Mitsubishi Motors (Thailand) Co., Ltd. This factory usually handles the production of vehicles like Pick-up, PPV (Pick-up passenger vehicle) and Eco-car. The activities of the factory include the following: (1) Pressing metal plate (Press section), (2) Spot-welding (Body section), (3) Painting and coating (Paint section), (4-8) Assembly section, (9-11) Quality-control section and (12) Test-drive section.

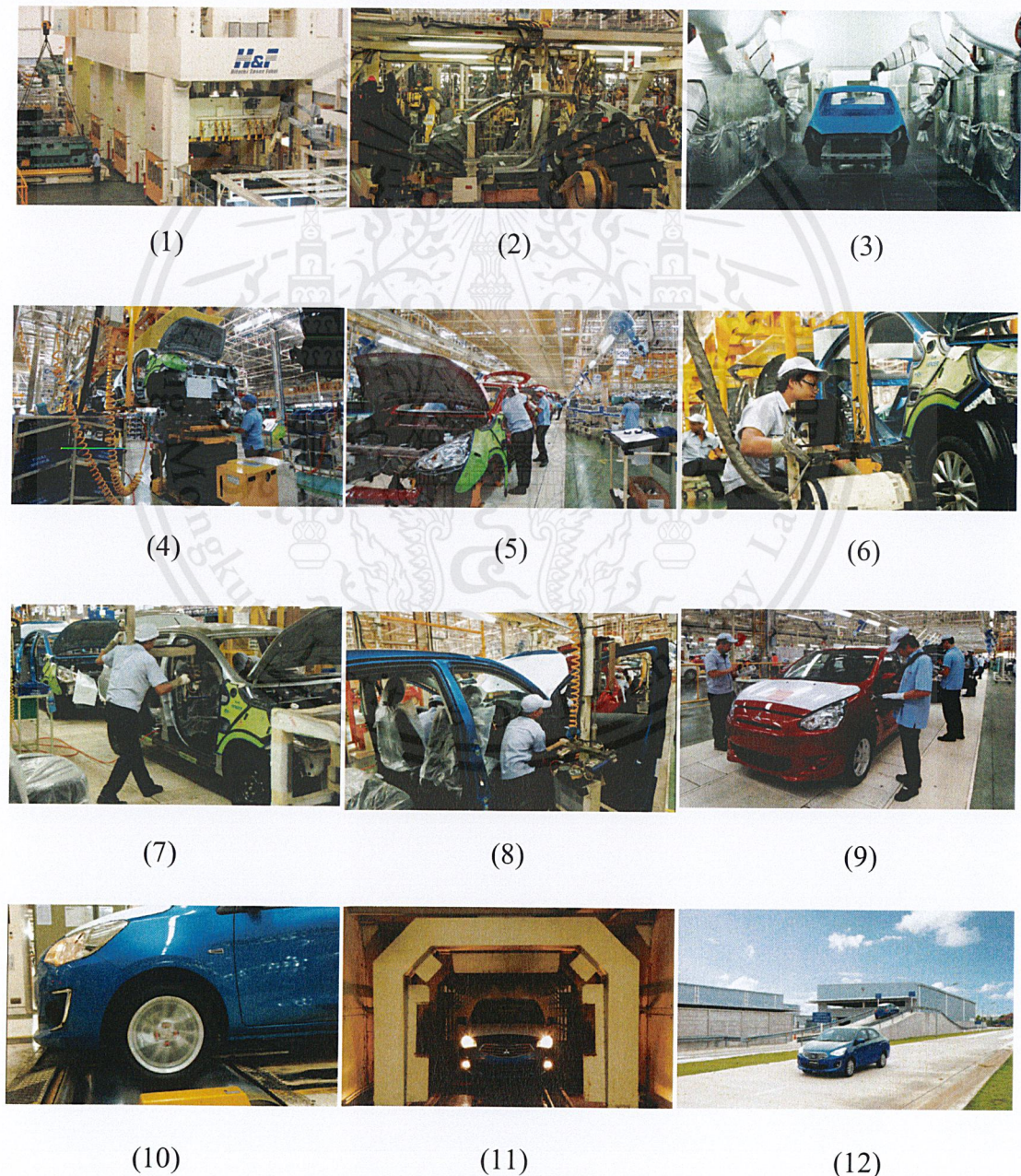


Figure 3.1 Overview of automotive production process

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3.2 Wastewater Survey

The wastewater is predominantly generated from the production process. In press section, the most of wastewater consists of oil & grease and a lot of scrap metal. These will have generated from cleaning the metal plate before pressing process. The body section, the wastewater from this section is the cooling water inside the spot-welding gun. In part of paint section, the large volume of wastewater will have generated from preparation the body car surface (Pretreatment), electrode deposition coating (ED), degreasing, primer coating, based coating, top coating and clear coating. The last one comes from the shower test (Leak investigation) at the quality-control section.

3.3 Collection and Preparation of Wastewater Sample

The Jar testing was carried out by sampling 500 mL of wastewater from V-notch tank (Flow adjustment) of ED/degreasing booth line & plastic factory (Line 1) and Phosphate line (Line 2). Plant-scale trial will sampling before reaction as mentioned above and after of the reaction that consists of Sedimentation tank no.1, Sedimentation tank no.3 and at Inspection pit will be collected too.

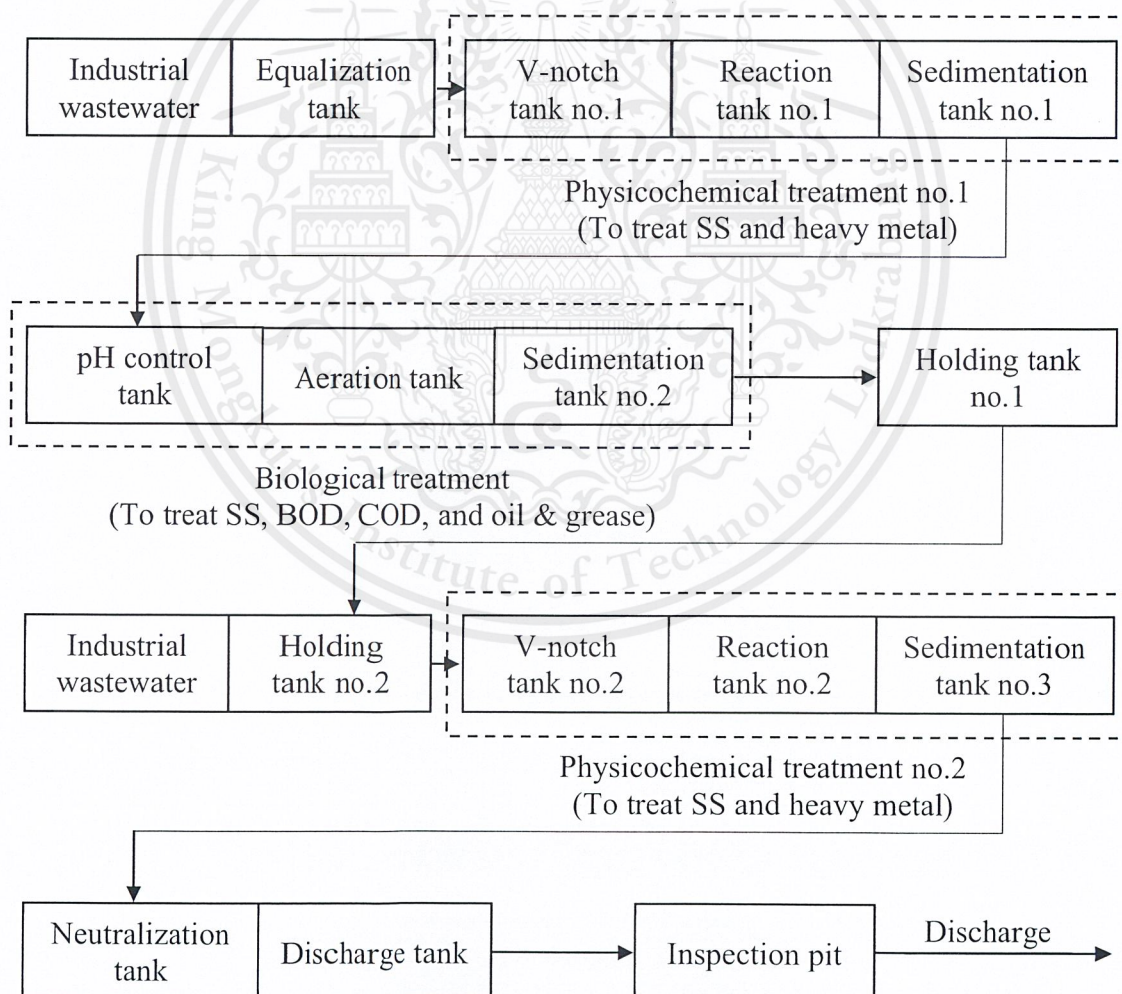


Figure 3.2 Wastewater treatment plant block diagram

3.4 Characterization of Wastewater

Different parameter like pH, suspended solid (SS), chemical oxygen demand (COD), biological oxygen demand (BOD) and heavy metal (Zn) of the sample were measured by the Global Utilities Services Co., Ltd. (GUSCO).

3.5 Equipment and Apparatus

1. Beakers
2. Graduated cylinder
3. Jar tester preferably 5 paddles
4. pH meter
5. Sampling bottles
6. Stirring rod
7. Syringes

3.6 Chemicals

1. Coagulants
 - (1) Ferric chloride (FeCl_3)
 - (2) PAC-C (COAG I-305)
2. Coagulants-aid
 - (1) Calcium hydroxide ($\text{Ca}(\text{OH})_2$)
 - (2) Polyacrylamide copolymer (Kurita ZA-301S)
3. Flocculant
 - (1) Anionic polyacrylamide (APAM/Kurita C-3310)

3.7 Experimental Procedure

1. First, the stock solution was prepared. A cylinder was used to grab sampling 500 mL of wastewater from V-notch tank to each of the jar test beakers. Then the stirrers were turned on and operated them at 500 RPM.

2. Next, the stock solution was used to dose each beaker with increased amounts of the solution and then the pH was adjusted to 9-10 of all jars while mixing by dosing $\text{Ca}(\text{OH})_2$. After dosing each beaker, the stirrers operated for 2 minutes to simulate the static mixer.

3. While the anionic polymer was dosed to each beaker, then the speed of the stirrers was reduced to 150 RPM and operated for 1 minutes. The floc formation was observed periodically during the 1 minute. At the end of the 1 minute the stirrers were turned off and allowed settling.

4. Finally, the beakers were looked and determined which one had the best results. If no results were noticeable, then the dosage for the next jars were increased. An underfeeding will cause the sample in the beaker to look cloudy with little or no floc and no settling. An overfeeding will cause a dense fluffy floc to form and will not settle well, meaning it stays in suspension and floats. The beaker that looks like it has the appropriate dosage will have floc that has settled to the bottom, and the water above it will be relatively clear.

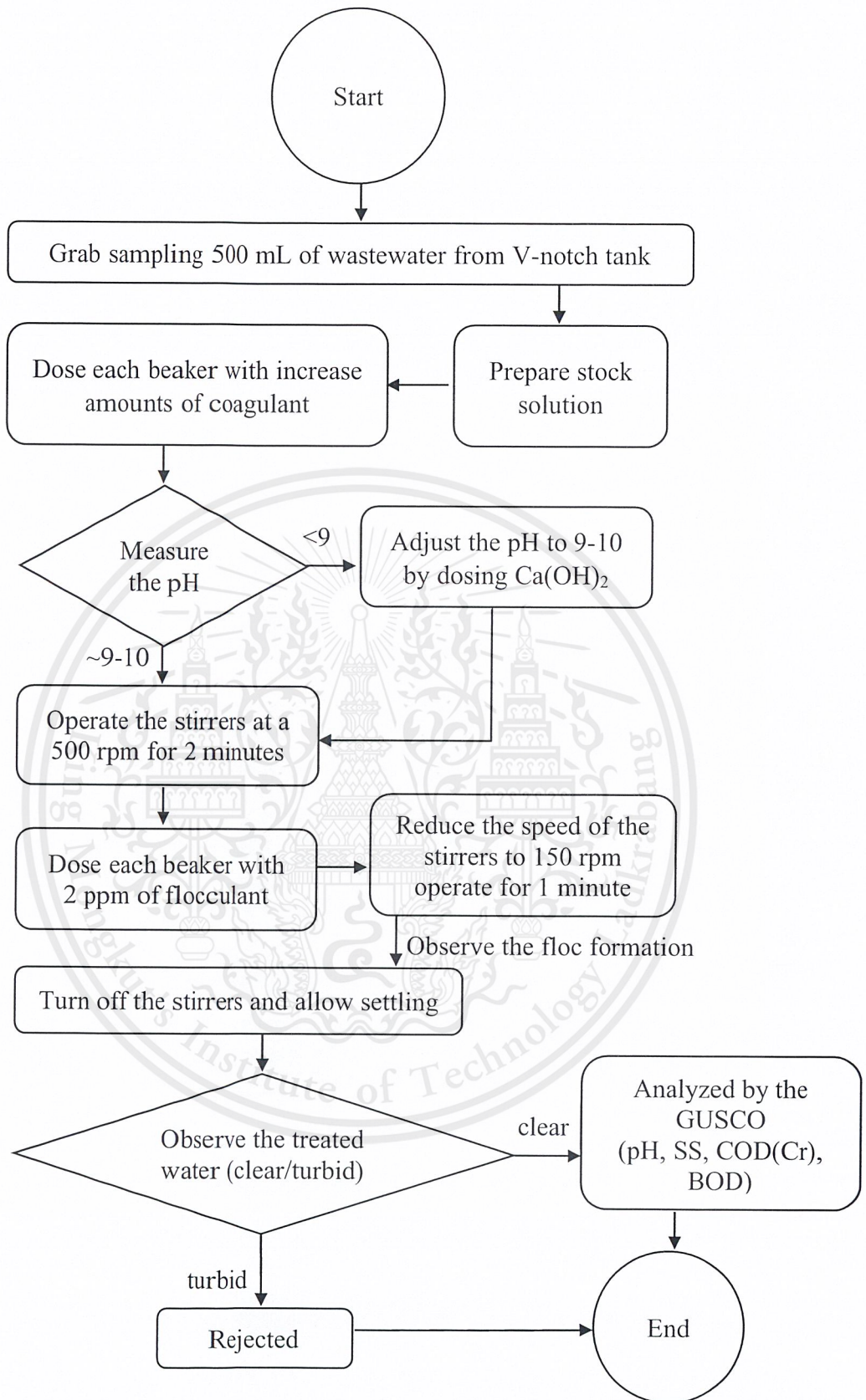


Figure 3.3 Experimental procedure flowchart

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Performance of Coagulation-Flocculation

In the coagulation-flocculation process, it was important to control pH since the coagulation occurs within a specific range for each coagulant. In this study, pH was fixed within the range of 9-10 by using $\text{Ca}(\text{OH})_2$. The experiment was proceeded by vary the PAC-C dosage, to determine the optimal dose. The jar testing was divided into line 1 and 2 of wastewater treatment system and this experiment was performed with the addition of fixed 2 ppm of APAM as a flocculant into each sample.

4.1.1 Various dosage of PAC-C in line 1

This part compared the performance of PAC-C at 50, 100, 150 and 200 ppm, respectively. The parameter values were compared SS, COD (Cr), BOD and heavy metal (Zn) level in term of percent removal. These were also plotted in Figure 4.1 and 4.2 and dry weight of floc was shown in Table 4.1 and 4.2 respectively.

The results showed that at 200 ppm of PAC-C, the percent removal of SS, COD (Cr), and BOD was 96.55, 73.27 and 90.34 respectively which was the highest removal efficiency. While heavy metal removal (Zn), the highest percent removal was 29.35 at 50 ppm but the percent removal of SS at 50 ppm was lower than 200 ppm, 8%. It would affect that treated wastewater was turbid. However, when comparing between 200 ppm and 100 ppm, there was little difference in percent removal. At 100 ppm, it has the lowest dry weight of floc. That would affect the less in sludge generation after treatment, which makes PAC-C at 100 ppm the optimal solution for wastewater treatment system in line 1.

Table 4.1

Comparison of percent removal and dry weight of floc by various PAC-C dosage

Dosage (ppm)	%Removal				Dry weight (g.)
	SS	COD (Cr)	BOD	Zinc	
50	88.70	71.60	87.06	29.35	0.0377
100	92.98	72.58	90.01	24.02	0.0323
150	94.36	72.75	88.22	19.68	0.0462
200	96.55	73.27	90.34	18.53	0.0478

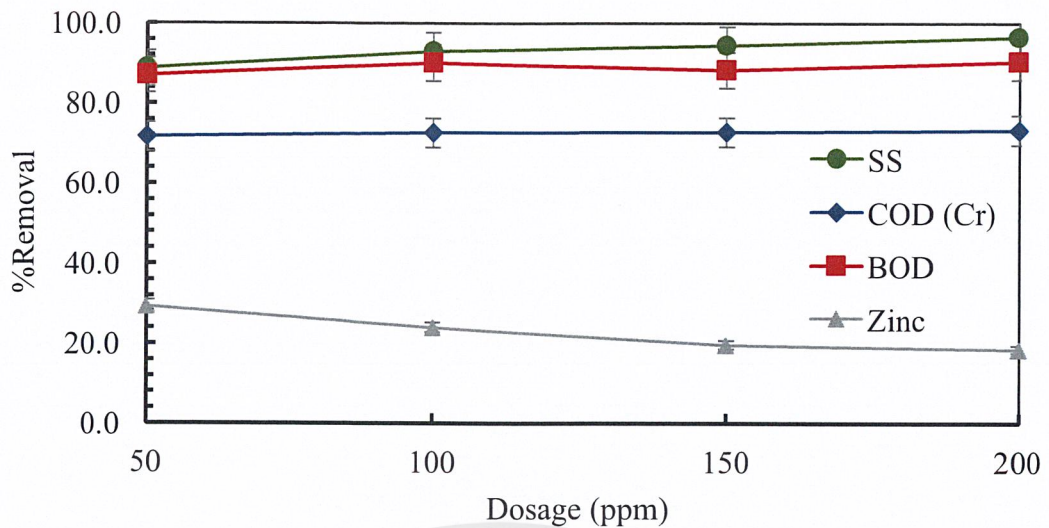


Figure 4.1 Performance of percent removal under various PAC-C dosage

4.1.2 Various dosage of PAC-C in line 2

The results of the experiment in line 2 were similar to the line 1. In Figure 4.2, it was found that at 100 ppm of PAC-C, the percent removal of SS, COD and heavy metal (Zn) level was close to the 200 ppm which was the highest value. At 100 ppm, not only was the highest BOD removal but also had the lowest dry weight of floc. Therefore, PAC-C at 100 ppm was chosen for line 2.

Table 4.2

Comparison of percent removal and dry weight of floc by various PAC-C dosage

Dosage (ppm)	%Removal				Dry weight (g.)
	SS	COD (Cr)	BOD	Zinc	
50	78.03	80.41	65.83	94.91	0.0400
100	88.42	80.88	72.21	94.85	0.0358
150	88.83	80.23	67.87	95.35	0.0361
200	89.92	81.42	67.51	94.29	0.0421

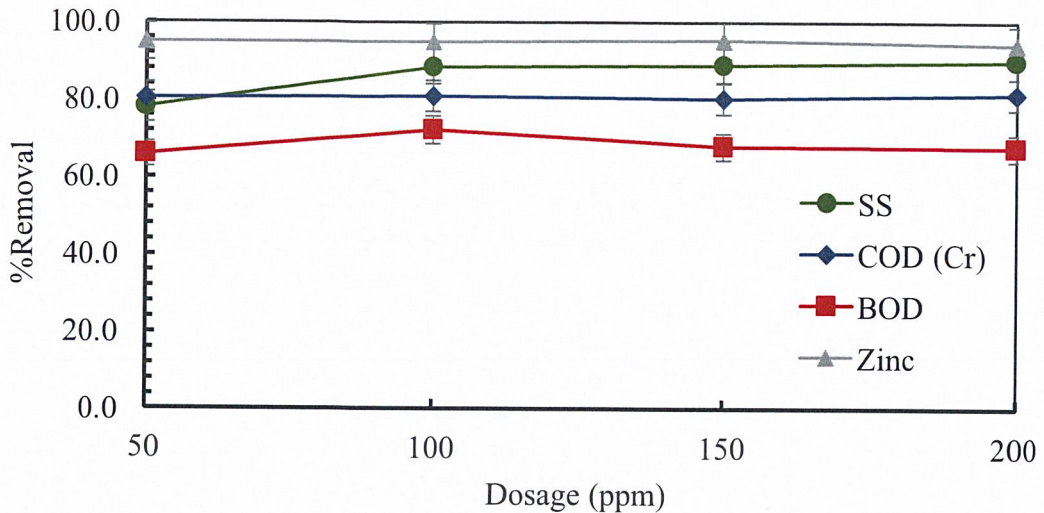


Figure 4.2 Performance of percent removal under various PAC-C dosage

4.2 Evaluation of PAC-C

4.2.1 Comparison with existing chemical treatment program in line 1

The performance of disposal in term of percent removal includes SS, COD (Cr), BOD and heavy metal (Zn) level was compared between Ferric chloride that is aided by Kurita ZA-301S (Existing chemical treatment program) and PAC-C (New chemical treatment program) to find out whether the PAC-C at 100 ppm is suitable to use in plant-scale.

In Figure 4.3 revealed that the new program tended to have a lower SS removal rate than the existing program which represents a value less than about 5% in Table 4.3. The Figure 4.4 and 4.5 showed similar trends in the removal of COD (Cr) and BOD. However, removal of heavy metals, the new program has a higher in 9% than the existing program and it has the less dry weight of floc.

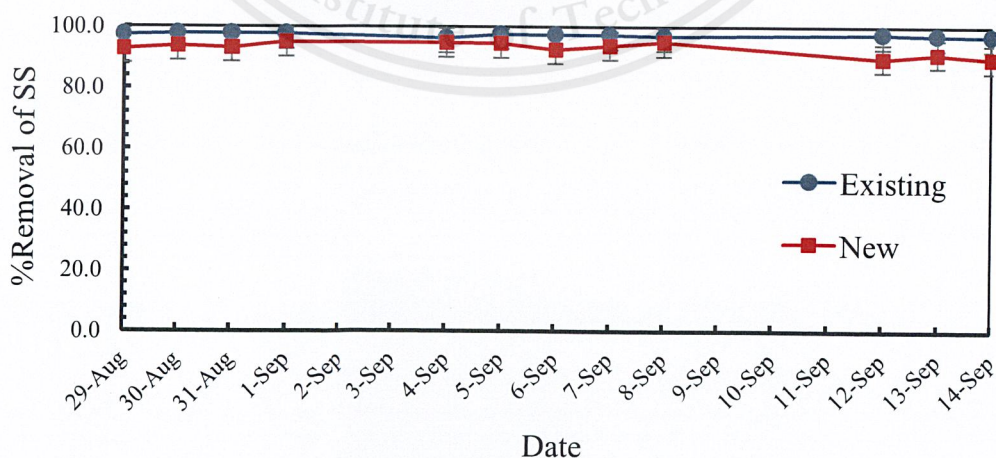


Figure 4.3 Performance of SS removal of comparison between existing and new chemical treatment program

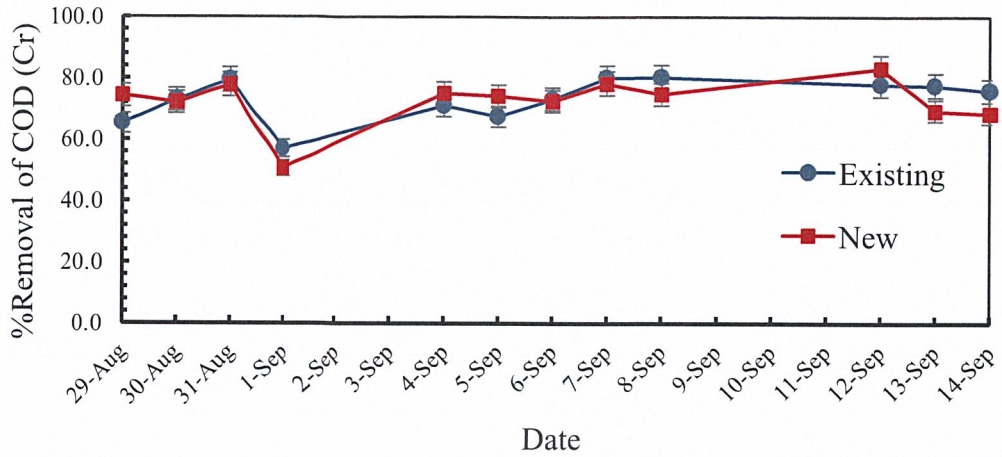


Figure 4.4 Performance of COD (Cr) removal of comparison between existing and new chemical treatment program

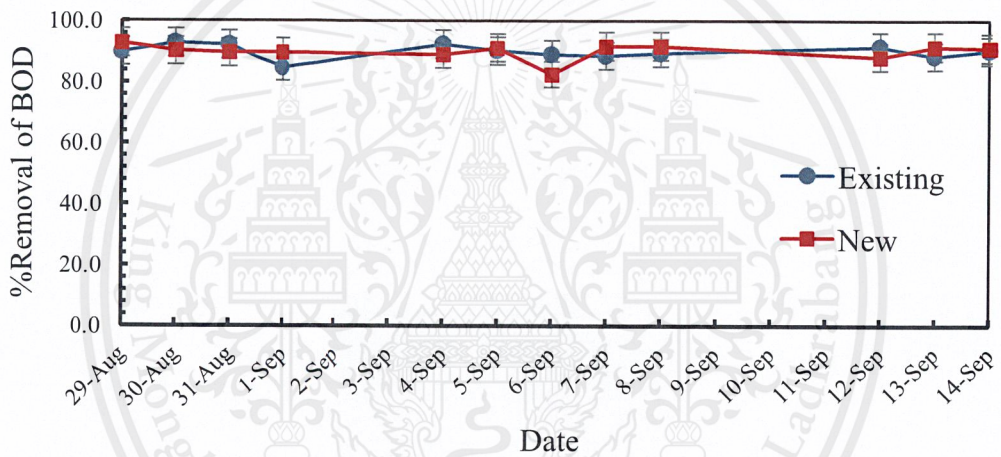


Figure 4.5 Performance of BOD removal of comparison between existing and new chemical treatment program

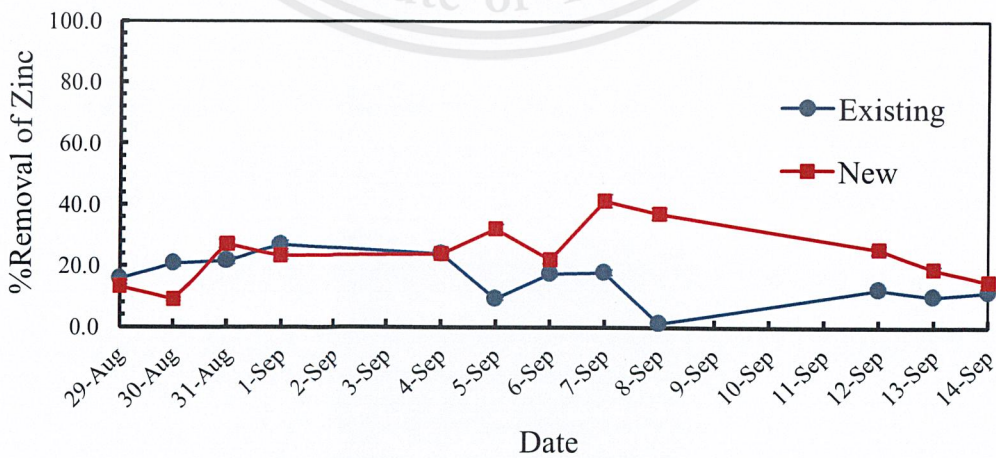


Figure 4.6 Performance of Zinc removal of comparison between existing and new chemical treatment program

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Table 4.3

Comparison between existing and new chemical treatment program

Program	%Removal				Dry weight (g.)
	SS	COD (Cr)	BOD	Zinc	
Existing	97.31	73.20	90.02	15.75	0.0356
New	92.98	72.58	90.01	24.02	0.0323

As a result of the Figure 4.3-4.6 and table 4.3, the tendency of wastewater treatment efficiency was similar. Therefore, in respect of the economics enclose chemical consumption and sludge disposal cost of existing and new program will be discussed in topic 4.4.

4.2.2 Comparison with existing chemical treatment program in line 2

The performance of parameters in term of percent removal includes SS, COD (Cr), BOD and heavy metal (Zn) level was compared between existing and new chemical treatment program for line 2.

Figure 4.7-4.8, it was found to be similar in SS, COD (Cr), BOD and heavy metal (Zn) level and the Table 4.4 showed that the new program and the existing program had a slightly different removal value. It was necessary to compare in the economic term as same as line 1.

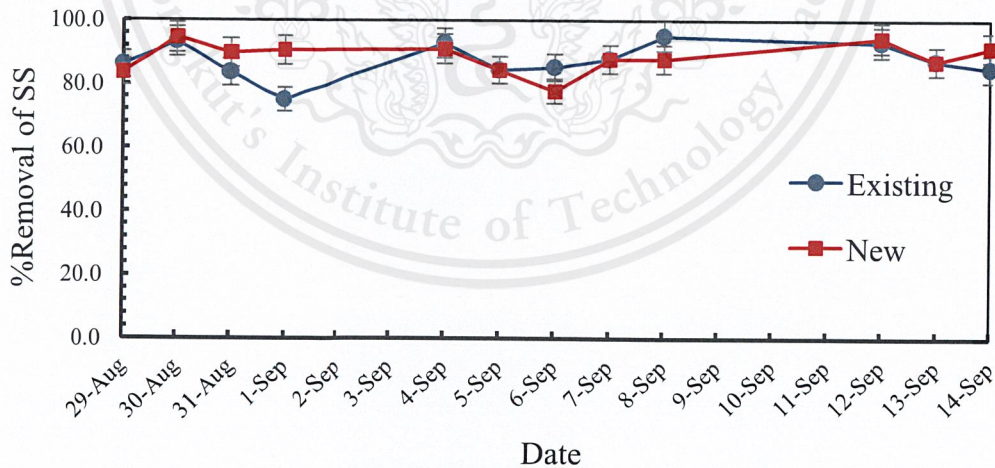


Figure 4.7 Performance of SS removal of comparison between existing and new chemical treatment program

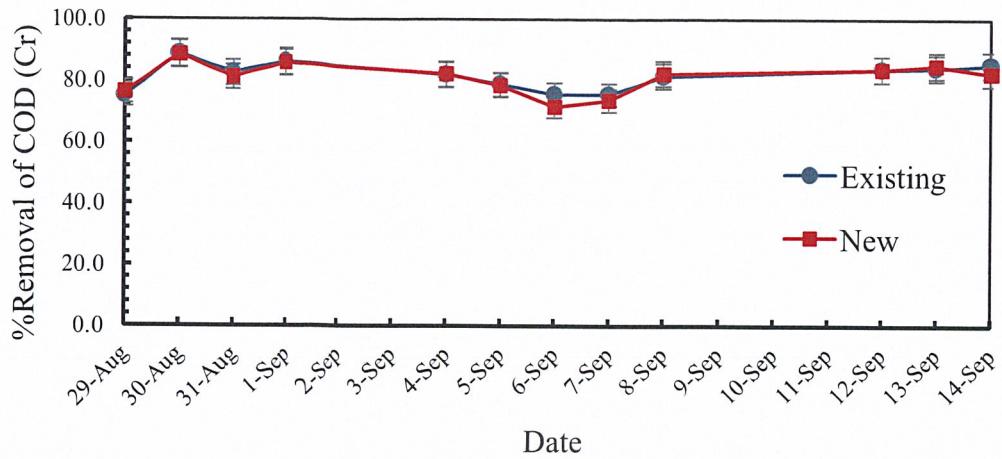


Figure 4.8 Performance of COD (Cr) removal of comparison between existing and new chemical treatment program

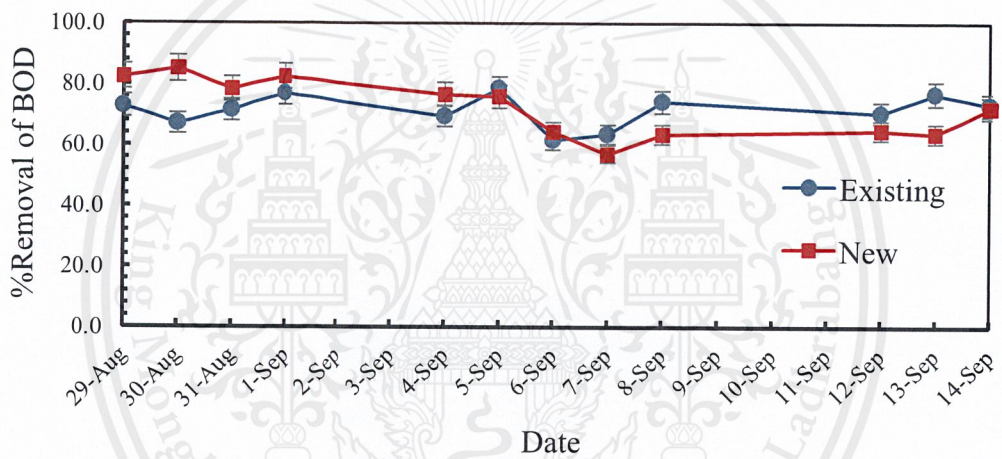


Figure 4.9 Performance of BOD removal of comparison between existing and new chemical treatment program

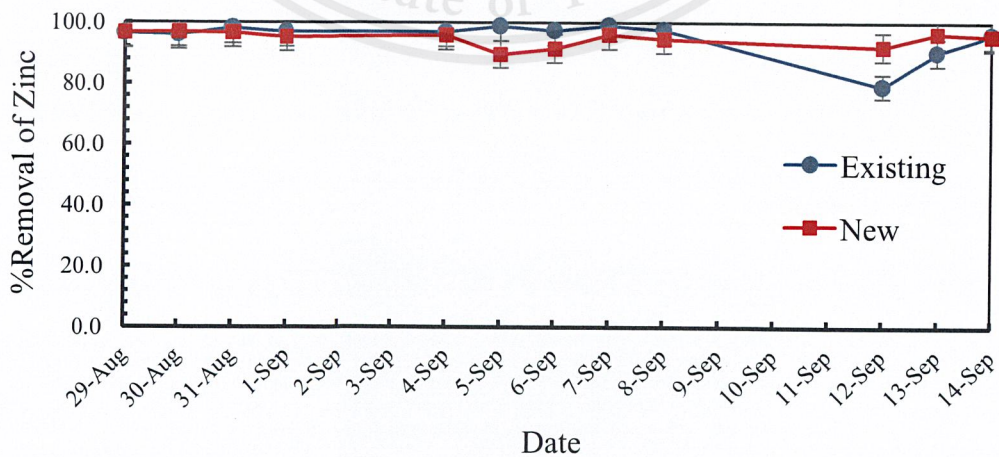


Figure 4.10 Performance of Zinc removal of comparison between existing and new chemical treatment program

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Table 4.4

Comparison between existing and new chemical treatment program

Program	%Removal				Dry weight (g.)
	SS	COD (Cr)	BOD	Zinc	
Existing	87.39	81.54	71.34	95.25	0.0381
New	88.42	80.88	72.21	94.85	0.0358

4.3 Standard of Treated Wastewater

The treated wastewater with the new program must be according to the IEAT. and Mitsubishi Motors Thailand (MMTh) standard. The results of the effluent analysis from the plant-scale trial was shown in Table A.26. Analyzed parameters were pH, SS, COD (Cr) and BOD. In Figure 4.11, the pH measured was in the standard range. Figures 4.12, 4.13 and 4.14 showed the SS, COD (Cr), and BOD respectively, that not exceeded the standard values. Therefore, the new chemical treatment program can be apply in the plant-scale.

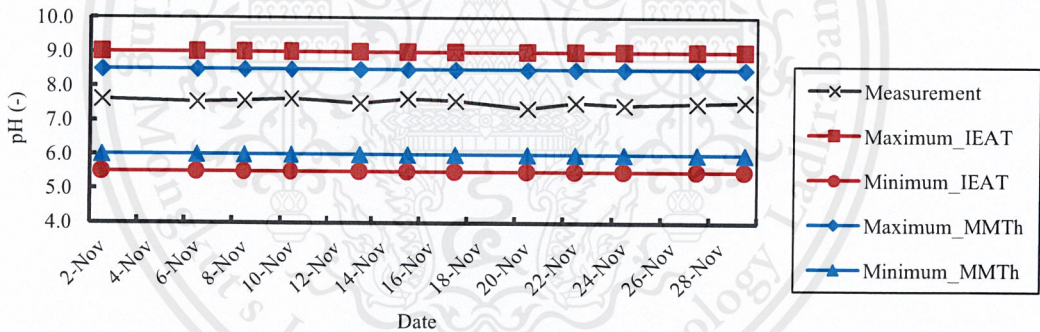


Figure 4.11 Performance of PAC-C (New Program) to control pH of effluent

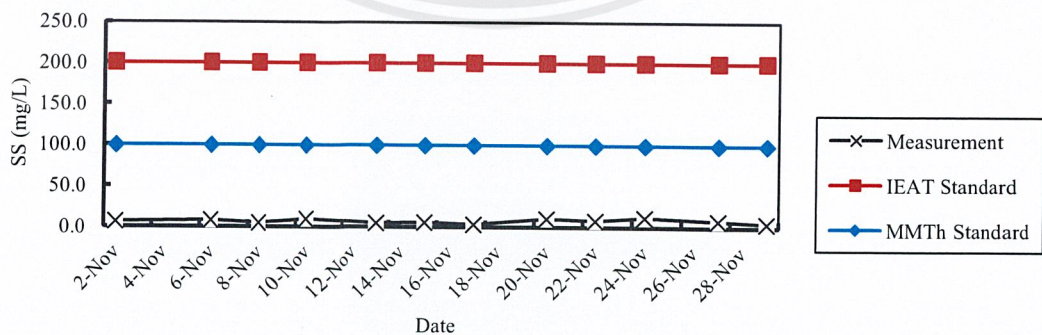


Figure 4.12 Performance of PAC-C (New Program) to control SS of effluent

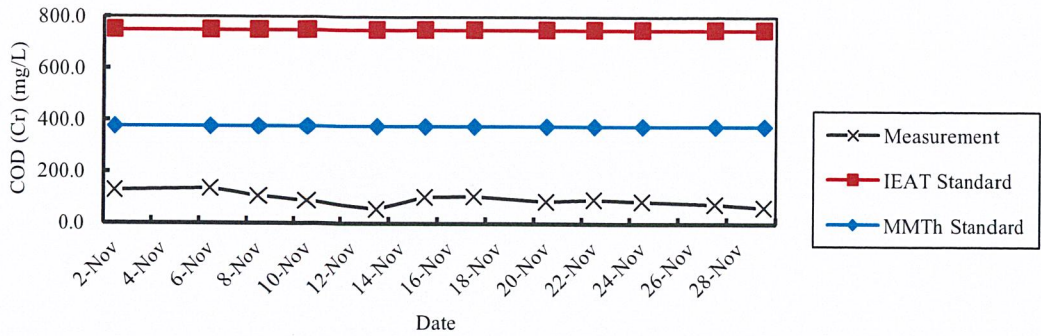


Figure 4.13 Performance of PAC-C (New Program) to control COD (Cr) of effluent

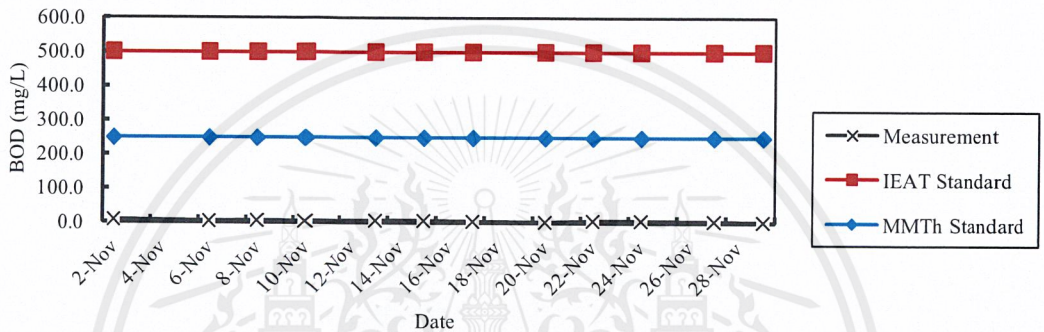


Figure 4.14 Performance of PAC-C (New Program) to control BOD of effluent

4.4 Operating Cost

The main operating costs was chemical consumption cost and sludge disposal cost. The summary of calculation table was shown at Appendix B and C respectively.

Cycle year 2016 and Nov'17 were chosen as the existing program and the new program data to compare the operating cost. In Table 4.5 showed the chemical consumption cost. The results found that the cost was decreased in 1.14 Bath/m³. Table 4.6 showed that the disposal cost was decreased in 0.08 Bath/m³. Therefore, the total operating cost was decreased in 1.22 Baht/m³ (Decrease in 9% of existing chemical treatment program) which based on total wastewater after treating with the new program.

Table 4.5

Comparison of chemical consumption cost

Year	Total wastewater (m ³)	Treatment cost (Baht)	Treatment cost/total wastewater (Baht/m ³)
2015	342,723.00	3,704,007.00	10.81
2016	335,689.00	3,634,951.51	10.83
2017	154,967.00	1,541,253.00	9.95
Nov'17	29,984.00	290,442.60	9.69

Table 4.6
Comparison of sludge disposal cost

Year	Total wastewater (m ³)	Treatment cost (Baht)	Treatment cost/total wastewater (Baht/m ³)
2015	342,723.00	872,820.90	2.55
2016	335,689.00	842,572.50	2.51
2017	154,967.00	387,807.00	2.50
Nov'17	29,984.00	72,828.00	2.43

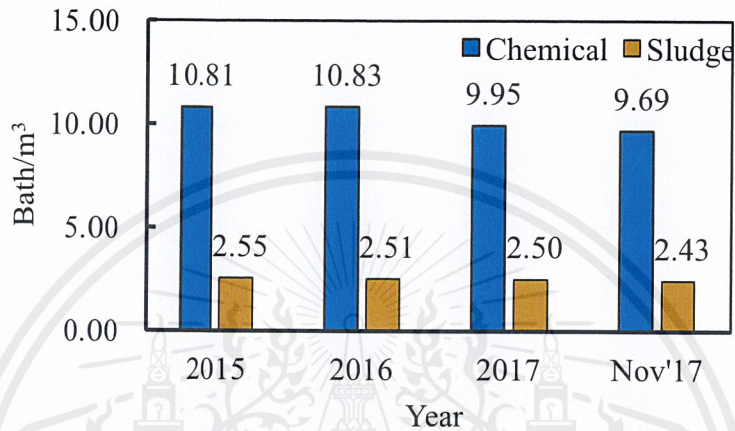


Figure 4.15 Total operating cost (Baht/m³)

4.5 Environmental Impact

Carbon dioxide (CO₂) affect an environmental. The CO₂ reduction was compared between the new program and existing program. The CO₂ emission was calculated by the amount of used chemical and amount of sludge was multiplied by CO₂ conversion coefficient from the quote guideline issued by the ministry of economy, trade & industry in Japan. It was shown in Appendix D.

Table 4.7 and Figure 4.16 showed that the emission of CO₂ in new program decreased by 35% compared to existing program.

Table 4.7
Comparison of carbon dioxide (CO₂) reduction

Item	Existing program	New program	Percentage difference
Coagulant	2292.86	1541.62	0.33
pH adjustment	3903.99	799.82	0.80
Flocculant	121.04	97.61	0.19
Sludge waste	4831.69	4837.86	0.00
Total CO ₂	11149.57	7,276.91	0.35

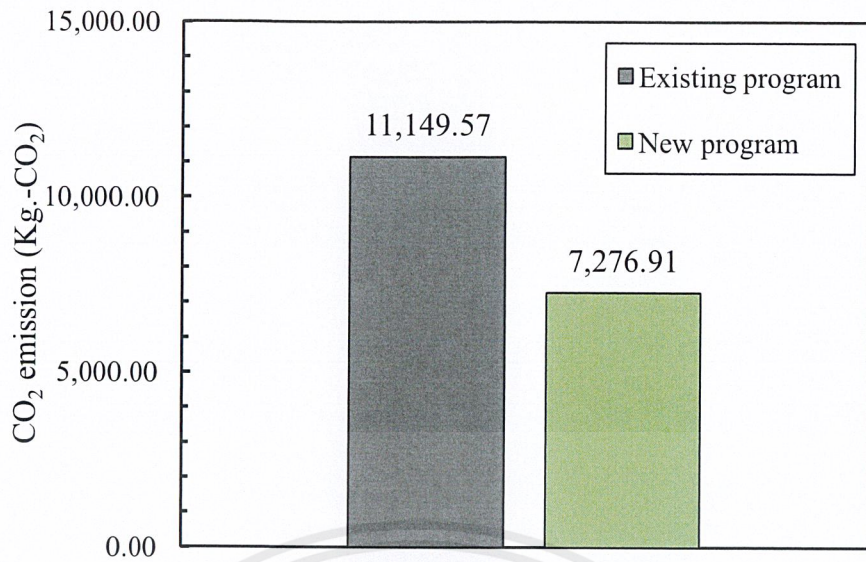
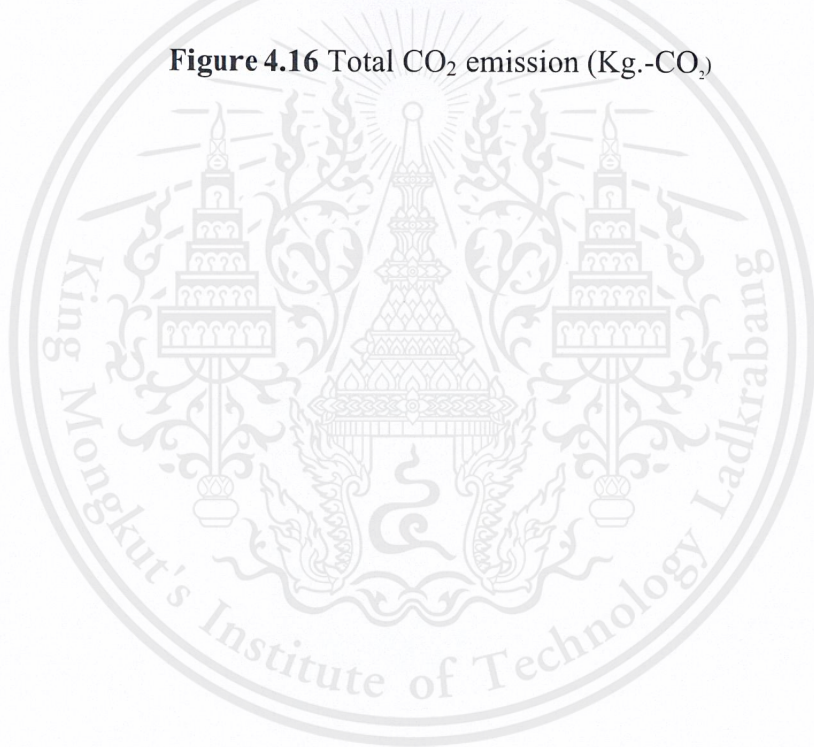


Figure 4.16 Total CO₂ emission (Kg.-CO₂)



CHAPTER V CONCLUSION

5.1 Conclusion

The optimal dose of PAC-C was 100 ppm for the wastewater treatment line 1 and 2 which resulted in effluent SS removal of 92.98%, 88.42%, COD removal of 72.58%, 80.88%, BOD removal of 90.01%, 72.21% and Zn removal of 24.02%, 94.85% for line 1 and 2 respectively. The effluent from the treatment process with PAC-C coagulant at 100 ppm as the new chemical treatment program reached the standard quality of IEAT. It also helped in the improvement of treatment process including the reduction of chemical consumption and the sludge generation after treating. The cost of chemicals and sludge disposal for the treatment of one cubic meter of wastewater was 12.12 Baht/m³. The results of this study were compared with existing chemical treatment program. The comparison implied that the use of coagulant aid could be reduced the total operation cost by 1.22 Baht/m³ which equaled to 9% of the total cost and Carbon dioxide (CO₂) emitted by 35% for comparable removal efficiencies.

5.2 Suggestion

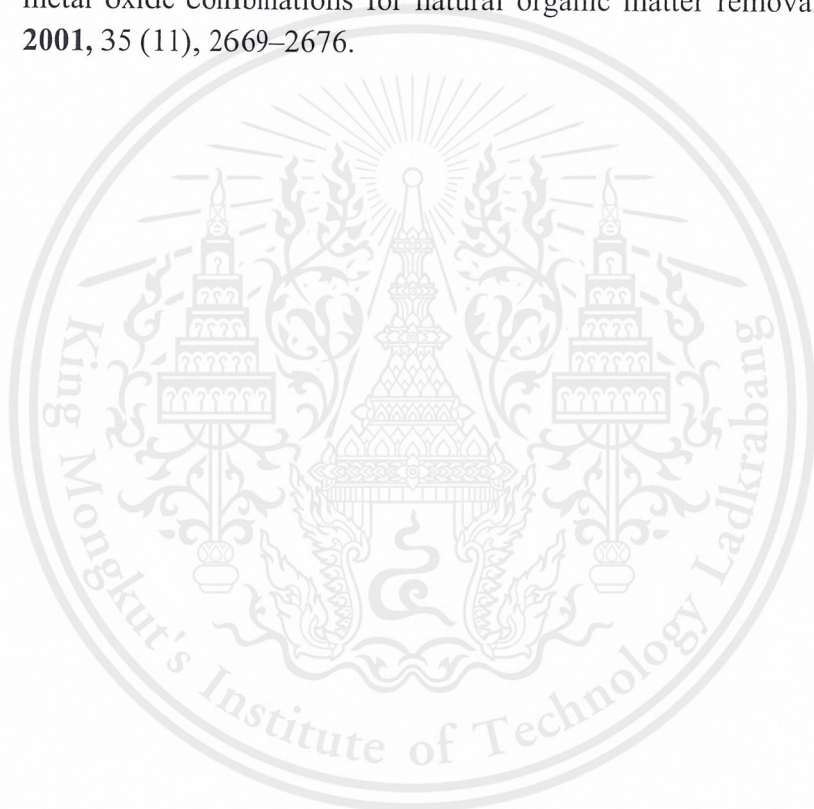
The operation on plant-scale, the chemical such as coagulant, chemical pH adjustment and flocculant need to mix well and dilute them with the same concentration value of this experiment.

For continuous improvement, inorganic coagulants and Calcium hydroxide may be canceled by using only the cationic polyelectrolyte as a primary coagulant but it may have a problem on pH which is not appropriate for coagulation of heavy metal therefore that coagulation will not occur.

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APPENDIX A

WASTEWATER ANALYSIS DATA

A.1 Data Analysis of Wastewater Treatment System Line 1

Table A.1

Parameter of untreated wastewater

No.	pH	SS	COD (Cr)	BOD	Zinc
1	7.03	88.00	643	308	1.52
2	6.75	112.00	759	392	1.68
3	6.83	98.00	954	338	1.66
4	6.90	103.00	482	195	1.72
5	7.21	83.00	745	321	1.63
6	6.94	118.00	650	298	1.50
7	6.32	94.00	721	304	1.55
8	7.13	86.00	954	327	1.62
9	7.01	102.00	884	307	1.64
10	6.86	83.00	921	289	1.53
11	6.77	91.00	866	311	1.58
12	6.94	87.00	758	318	1.55

Table A.2

Parameter of treated wastewater by FeCl_3 at 200 ppm with Kurita ZA-301S at 5 ppm

No.	pH	SS	COD (Cr)	BOD	Zinc	Dry weight
1	10.02	2.33	223	31	1.28	0.0364
2	10.05	2.54	205	28	1.33	0.0372
3	9.96	2.15	196	26	1.30	0.0366
4	9.89	2.36	207	30	1.26	0.0318
5	10.11	3.06	216	24	1.24	0.0379
6	10.32	2.81	211	29	1.36	0.0312
7	10.04	2.44	193	33	1.28	0.0347
8	9.56	2.32	190	37	1.33	0.0401

No.	pH	SS	COD (Cr)	BOD	Zinc	Dry weight
9	9.94	3.15	174	32	1.62	0.0321
10	10.04	1.97	203	24	1.34	0.0367
11	10.21	2.64	194	36	1.42	0.0381
12	10.15	2.71	183	31	1.37	0.0341

Table A.3

Parameter of treated wastewater by PAC-C at 200 ppm

No.	pH	SS	COD (Cr)	BOD	Zinc	Dry weight
1	10.15	3.62	173	31	1.36	0.0425
2	10.36	2.54	205	28	1.34	0.0436
3	10.28	2.66	216	34	1.28	0.0387
4	9.94	2.38	203	32	1.20	0.0366
5	9.63	3.15	198	30	1.29	0.0342
6	9.88	3.16	204	28	1.26	0.0635
7	9.92	3.28	186	26	1.36	0.0522
8	9.93	3.24	206	22	1.22	0.0578
9	10.05	3.16	193	37	1.36	0.0534
10	10.16	3.74	188	28	1.28	0.0463
11	9.94	3.63	213	21	1.29	0.0512
12	9.97	4.05	227	31	1.35	0.0537

Table A.4

Parameter of treated wastewater by PAC-C at 150 ppm

No.	pH	SS	COD (Cr)	BOD	Zinc	Dry weight
1	10.01	5.42	156	22	1.21	0.0439
2	10.21	4.88	221	40	1.55	0.0477
3	10.13	5.76	216	35	1.32	0.0462
4	9.95	6.12	226	38	1.21	0.0501

No.	pH	SS	COD (Cr)	BOD	Zinc	Dry weight
5	10.05	3.12	194	41	1.32	0.0486
6	10.12	5.34	177	32	1.12	0.0463
7	9.87	5.08	193	48	1.54	0.0511
8	10.13	5.21	194	37	1.13	0.0328
9	10.21	6.03	201	34	1.20	0.0471
10	10.14	5.32	196	38	1.21	0.0453
11	9.95	4.76	259	25	1.13	0.0439
12	10.04	7.03	226	36	1.45	0.0517

Table A.5

Parameter of treated wastewater by PAC-C at 100 ppm

No.	pH	SS	COD (Cr)	BOD	Zinc	Dry weight
1	10.04	6.34	165	22	1.32	0.0322
2	10.02	7.03	212	38	1.53	0.0363
3	10.11	6.74	211	35	1.21	0.0297
4	9.43	5.12	238	20	1.32	0.0301
5	9.89	4.32	186	35	1.24	0.0317
6	10.21	6.43	168	26	1.02	0.0347
7	10.05	7.05	198	53	1.21	0.0354
8	10.10	5.32	207	27	0.95	0.0284
9	10.09	5.11	223	25	1.03	0.0316
10	9.95	8.56	154	34	1.14	0.0372
11	9.82	8.04	265	26	1.28	0.0292
12	10.02	9.11	238	28	1.32	0.0308

Table A.6

Parameter of treated wastewater by PAC-C at 50 ppm

No.	pH	SS	COD (Cr)	BOD	Zinc	Dry weight
1	9.98	8.43	194	33	1.12	0.0325
2	10.02	10.30	214	56	1.09	0.0385
3	10.11	9.55	223	42	1.11	0.0347
4	10.04	11.21	187	45	1.11	0.0382
5	9.86	10.08	195	33	1.17	0.0388
6	9.88	9.50	165	31	1.13	0.0359
7	9.96	12.40	207	56	1.12	0.0401
8	10.06	13.20	245	34	1.09	0.0381
9	10.08	8.60	216	34	1.12	0.0348
10	9.93	9.65	232	31	1.18	0.0402
11	9.97	10.87	283	35	1.12	0.0429
12	10.03	13.42	243	39	1.16	0.0379

A.2 Percentage Removal of Wastewater Treatment System Line 1**Table A.7**Percentage removal of treated wastewater by FeCl_3 at 200 ppm with Kurita ZA-301S at 5 ppm

No.	SS			COD (Cr)		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	88.00	2.33	97.35	643	223	65.32
2	112.00	2.54	97.73	759	205	72.99
3	98.00	2.15	97.81	954	196	79.45
4	103.00	2.36	97.71	482	207	57.05
5	83.00	3.06	96.31	745	216	71.01
6	118.00	2.81	97.62	650	211	67.54
7	94.00	2.44	97.40	721	193	73.23
8	86.00	2.32	97.30	954	190	80.08

No.	SS			COD (Cr)		
	Initial	Residual	%Removal	Initial	Residual	%Removal
9	102.00	3.15	96.91	884	174	80.32
10	83.00	1.97	97.63	921	203	77.96
11	91.00	2.64	97.10	866	194	77.60
12	87.00	2.71	96.89	758	183	75.86

No.	BOD			Zinc		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	308	31	89.94	1.52	1.28	15.79
2	392	28	92.86	1.68	1.33	20.83
3	338	26	92.31	1.66	1.30	21.69
4	195	30	84.62	1.72	1.26	26.74
5	321	24	92.52	1.63	1.24	23.93
6	298	29	90.27	1.50	1.36	9.33
7	304	33	89.14	1.55	1.28	17.42
8	327	37	88.69	1.62	1.33	17.90
9	307	32	89.58	1.64	1.62	1.22
10	289	24	91.70	1.53	1.34	12.42
11	311	36	88.42	1.58	1.42	10.13
12	318	31	90.25	1.55	1.37	11.61

Table A.8

Percentage removal of treated wastewater by PACC at 200 ppm

No.	SS			COD (Cr)		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	88.00	3.62	95.89	643	173	73.09
2	112.00	2.54	97.73	759	205	72.99
3	98.00	2.66	97.29	954	216	77.36
4	103.00	2.38	97.69	482	203	57.88

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No.	SS			COD (Cr)		
	Initial	Residual	%Removal	Initial	Residual	%Removal
5	83.00	3.15	96.20	745	198	73.42
6	118.00	3.16	97.32	650	204	68.62
7	94.00	3.28	96.51	721	186	74.20
8	86.00	3.24	96.23	954	206	78.41
9	102.00	3.16	96.90	884	193	78.17
10	83.00	3.74	95.49	921	188	79.59
11	91.00	3.63	96.01	866	213	75.40
12	87.00	4.05	95.34	758	227	70.05

No.	BOD			Zinc		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	308	31	89.94	1.52	1.36	10.53
2	392	28	92.86	1.68	1.34	20.24
3	338	34	89.94	1.66	1.28	22.89
4	195	32	83.59	1.72	1.20	30.23
5	321	30	90.65	1.63	1.29	20.86
6	298	28	90.60	1.50	1.26	16.00
7	304	26	91.45	1.55	1.36	12.26
8	327	22	93.27	1.62	1.22	24.69
9	307	37	87.95	1.64	1.36	17.07
10	289	28	90.31	1.53	1.28	16.34
11	311	21	93.25	1.58	1.29	18.35
12	318	31	90.25	1.55	1.35	12.90

Table A.9

Percentage removal of treated wastewater by PACC at 150 ppm

No.	SS		%Removal	COD (Cr)		%Removal
	Initial	Residual		Initial	Residual	
1	88.00	5.42	93.84	643	156	75.74
2	112.00	4.88	95.64	759	221	70.88
3	98.00	5.76	94.12	954	216	77.36
4	103.00	6.12	94.06	482	226	53.11
5	83.00	3.12	96.24	745	194	73.96
6	118.00	5.34	95.47	650	177	72.77
7	94.00	5.08	94.60	721	193	73.23
8	86.00	5.21	93.94	954	194	79.66
9	102.00	6.03	94.09	884	201	77.26
10	83.00	5.32	93.59	921	196	78.72
11	91.00	4.76	94.77	866	259	70.09
12	87.00	7.03	91.92	758	226	70.18

No.	BOD		%Removal	Zinc		%Removal
	Initial	Residual		Initial	Residual	
1	308	22	92.86	1.52	1.21	20.39
2	392	40	89.80	1.68	1.55	7.74
3	338	35	89.64	1.66	1.32	20.48
4	195	38	80.51	1.72	1.21	29.65
5	321	41	87.23	1.63	1.32	19.02
6	298	32	89.26	1.50	1.12	25.33
7	304	48	84.21	1.55	1.54	0.65
8	327	37	88.69	1.62	1.13	30.25
9	307	34	88.93	1.64	1.20	26.83
10	289	38	86.85	1.53	1.21	20.92

No.	SS		%Removal	COD (Cr)		%Removal
	Initial	Residual		Initial	Residual	
11	311	25	91.96	1.58	1.13	28.48
12	318	36	88.68	1.55	1.45	6.45

Table A.10

Percentage removal of treated wastewater by PACC at 100 ppm

No.	SS		%Removal	COD (Cr)		%Removal
	Initial	Residual		Initial	Residual	
1	88.00	6.34	92.80	643	165	74.34
2	112.00	7.03	93.72	759	212	72.07
3	98.00	6.74	93.12	954	211	77.88
4	103.00	5.12	95.03	482	238	50.62
5	83.00	4.32	94.80	745	186	75.03
6	118.00	6.43	94.55	650	168	74.15
7	94.00	7.05	92.50	721	198	72.54
8	86.00	5.32	93.81	954	207	78.30
9	102.00	5.11	94.99	884	223	74.77
10	83.00	8.56	89.69	921	154	83.28
11	91.00	8.04	91.16	866	265	69.40
12	87.00	9.11	89.53	758	238	68.60

No.	BOD		%Removal	Zinc		%Removal
	Initial	Residual		Initial	Residual	
1	308	22	92.86	1.52	1.32	13.16
2	392	38	90.31	1.68	1.53	8.93
3	338	35	89.64	1.66	1.21	27.11
4	195	20	89.74	1.72	1.32	23.26
5	321	35	89.10	1.63	1.24	23.93
6	298	26	91.28	1.50	1.02	32.00

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No.	SS			COD (Cr)		
	Initial	Residual	%Removal	Initial	Residual	%Removal
7	304	53	82.57	1.55	1.21	21.94
8	327	27	91.74	1.62	0.95	41.36
9	307	25	91.86	1.64	1.03	37.20
10	289	34	88.24	1.53	1.14	25.49
11	311	26	91.64	1.58	1.28	18.99
12	318	28	91.19	1.55	1.32	14.84

Table A.11

Percentage removal of treated wastewater by PACC at 50 ppm

No.	SS			COD (Cr)		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	88.00	8.43	90.42	643	194	69.83
2	112.00	10.30	90.80	759	214	71.81
3	98.00	9.55	90.26	954	223	76.62
4	103.00	11.21	89.12	482	187	61.20
5	83.00	10.08	87.86	745	195	73.83
6	118.00	9.50	91.95	650	165	74.62
7	94.00	12.40	86.81	721	207	71.29
8	86.00	13.20	84.65	954	245	74.32
9	102.00	8.60	91.57	884	216	75.57
10	83.00	9.65	88.37	921	232	74.81
11	91.00	10.87	88.05	866	283	67.32
12	87.00	13.42	84.57	758	243	67.94

No.	BOD			Zinc		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	308	33	89.29	1.52	1.12	26.32
2	392	56	85.71	1.68	1.09	35.12

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No.	SS			COD (Cr)		
	Initial	Residual	%Removal	Initial	Residual	%Removal
3	338	42	87.57	1.66	1.11	33.13
4	195	45	76.92	1.72	1.11	35.47
5	321	33	89.72	1.63	1.17	28.22
6	298	31	89.60	1.50	1.13	24.67
7	304	56	81.58	1.55	1.12	27.74
8	327	34	89.60	1.62	1.09	32.72
9	307	34	88.93	1.64	1.12	31.71
10	289	31	89.27	1.53	1.18	22.88
11	311	35	88.75	1.58	1.12	29.11
12	318	39	87.74	1.55	1.16	25.16

A.3 Data Analysis of Wastewater Treatment System Line 2

Table A.12

Parameter of untreated wastewater

No.	pH	SS	COD (Cr)	BOD	Zinc
1	7.21	43.00	342	103	2.83
2	7.32	75.00	671	94	2.04
3	6.84	49.00	488	116	2.15
4	6.63	32.00	583	183	1.94
5	7.47	56.00	492	154	2.66
6	7.23	32.00	377	182	1.83
7	6.91	27.00	294	112	1.88
8	7.04	33.00	264	93	2.04
9	7.32	41.00	366	85	2.07
10	7.50	73.00	437	122	1.92
11	6.83	55.00	516	138	2.05
12	6.62	59.00	472	104	2.11

Table A.13Parameter of treated wastewater by FeCl₃ at 120 ppm with Kurita ZA-301S at 5 ppm

No.	pH	SS	COD (Cr)	BOD	Zinc	Dry weight
1	9.93	6.00	85	28	0.10	0.0323
2	9.96	5.00	76	31	0.08	0.0376
3	10.11	8.00	85	33	0.04	0.0432
4	10.23	8.00	81	42	0.06	0.0388
5	9.95	4.00	89	47	0.08	0.0352
6	9.85	5.00	80	39	0.02	0.0392
7	10.01	4.00	72	43	0.05	0.0401
8	10.07	4.00	65	34	0.02	0.0423
9	10.13	<2	68	22	0.05	0.0311
10	10.24	5.00	71	36	0.40	0.0349
11	9.92	7.00	82	32	0.20	0.0417
12	9.97	9.00	70	28	0.08	0.0406

Table A.14

Parameter of treated wastewater by PACC at 200 ppm

No.	pH	SS	COD (Cr)	BOD	Zinc	Dry weight
1	10.05	4.00	81	17	0.06	0.0412
2	10.16	3.00	85	15	0.05	0.0433
3	9.96	5.00	90	23	0.16	0.0456
4	9.83	3.00	74	18	0.18	0.0369
5	9.94	8.00	73	33	0.04	0.0338
6	10.15	6.00	70	60	0.16	0.0332
7	10.16	6.00	68	51	0.11	0.0384
8	9.88	4.00	86	44	0.22	0.0415
9	9.68	5.00	62	45	0.07	0.0463
10	10.24	6.00	88	43	0.03	0.0471
11	10.34	7.00	71	61	0.16	0.0508

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12	9.93	5.00	73	50	0.16	0.0465
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Table A.15

Parameter of treated wastewater by PACC at 150 ppm

No.	pH	SS	COD (Cr)	BOD	Zinc	Dry weight
1	10.21	6.00	85	23	0.11	0.0354
2	10.10	4.00	80	20	0.13	0.0285
3	10.24	5.00	88	19	0.11	0.0311
4	9.94	5.00	73	30	0.08	0.0291
5	9.86	5.00	72	39	0.09	0.0406
6	10.02	3.00	93	55	0.14	0.0329
7	10.15	5.00	85	47	0.12	0.0417
8	9.93	6.00	81	46	0.06	0.0418
9	9.88	3.00	71	50	0.10	0.0375
10	9.96	4.00	90	35	0.12	0.0382
11	10.10	6.00	80	58	0.05	0.0319
12	10.01	6.00	73	34	0.05	0.0449

Table A.16

Parameter of treated wastewater by PACC at 100 ppm

No.	pH	SS	COD (Cr)	BOD	Zinc	Dry weight
1	9.93	7.00	81	18	0.09	0.0384
2	9.95	4.00	77	14	0.06	0.0353
3	9.82	5.00	92	25	0.07	0.0356
4	10.03	3.00	83	32	0.09	0.0361
5	10.16	5.00	88	36	0.11	0.0342
6	10.06	5.00	81	44	0.19	0.0362
7	9.91	6.00	84	40	0.16	0.0351
8	10.19	4.00	70	40	0.08	0.0379
9	9.88	5.00	65	31	0.11	0.0402

10	10.02	4.00	71	43	0.15	0.0325
11	10.32	7.00	78	50	0.07	0.0329
12	10.11	5.00	83	29	0.09	0.0347

Table A.17

Parameter of treated wastewater by PACC at 50 ppm

No.	pH	SS	COD (Cr)	BOD	Zinc	Dry weight
1	10.07	11.00	90	25	0.12	0.0402
2	10.24	14.00	82	26	0.07	0.0382
3	9.93	12.00	91	29	0.06	0.0432
4	9.96	8.00	73	36	0.10	0.0365
5	10.12	9.00	77	62	0.13	0.0371
6	10.08	10.00	83	49	0.08	0.0412
7	10.04	13.00	79	56	0.11	0.0382
8	10.15	8.00	84	38	0.07	0.0318
9	9.93	5.00	70	45	0.15	0.0395
10	9.85	6.00	75	43	0.11	0.0482
11	10.02	8.00	88	37	0.16	0.0419
12	10.13	9.00	74	42	0.13	0.0437

A.4 Percentage Removal of Wastewater Treatment System Line 2**Table A.18**Percentage removal of treated wastewater by FeCl_3 at 120 ppm with Kurita ZA-301S at 5 ppm

No.	SS		%Removal	COD (Cr)		%Removal
	Initial	Residual		Initial	Residual	
1	43.00	6.00	86.05	342	85	75.15
2	75.00	5.00	93.33	671	76	88.67
3	49.00	8.00	83.67	488	85	82.58
4	32.00	8.00	75.00	583	81	86.11
5	56.00	4.00	92.86	492	89	81.91

6	32.00	5.00	84.38	377	80	78.78
7	27.00	4.00	85.19	294	72	75.51
8	33.00	4.00	87.88	264	65	75.38
9	41.00	<2	95.12	366	68	81.42
10	73.00	5.00	93.15	437	71	83.75
11	55.00	7.00	87.27	516	82	84.11
12	59.00	9.00	84.75	472	70	85.17

No.	BOD			Zinc		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	103	28	72.82	2.83	0.10	96.47
2	94	31	67.02	2.04	0.08	96.08
3	116	33	71.55	2.15	0.04	98.14
4	183	42	77.05	1.94	0.06	96.91
5	154	47	69.48	2.66	0.08	96.99
6	182	39	78.57	1.83	0.02	98.91
7	112	43	61.61	1.88	0.05	97.34
8	93	34	63.44	2.04	0.02	99.02
9	85	22	74.12	2.07	0.05	97.58
10	122	36	70.49	1.92	0.40	79.17
11	138	32	76.81	2.05	0.20	90.24
12	104	28	73.08	2.11	0.08	96.21

Table A.19

Percentage removal of treated wastewater by PACC at 200 ppm

No.	SS			COD (Cr)		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	43.00	4.00	90.70	342	81	76.32
2	75.00	3.00	96.00	671	85	87.33
3	49.00	5.00	89.80	488	90	81.56

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No.	SS			COD (Cr)		
	Initial	Residual	%Removal	Initial	Residual	%Removal
4	32.00	3.00	90.63	583	74	87.31
5	56.00	8.00	85.71	492	73	85.16
6	32.00	6.00	81.25	377	70	81.43
7	27.00	6.00	92.59	294	68	76.87
8	33.00	4.00	93.94	264	86	67.42
9	41.00	5.00	87.80	366	62	83.06
10	73.00	6.00	91.78	437	88	79.86
11	55.00	7.00	87.27	516	71	86.24
12	59.00	5.00	91.53	472	73	84.53

No.	BOD			Zinc		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	103	17	83.50	2.83	0.06	97.88
2	94	15	84.04	2.04	0.05	97.55
3	116	23	80.17	2.15	0.16	92.56
4	183	18	90.16	1.94	0.18	90.72
5	154	33	78.57	2.66	0.04	98.50
6	182	60	67.03	1.83	0.16	91.26
7	112	51	54.46	1.88	0.11	94.15
8	93	44	52.69	2.04	0.22	89.22
9	85	45	47.06	2.07	0.07	96.62
10	122	43	64.75	1.92	0.03	98.44
11	138	61	55.80	2.05	0.16	92.20
12	104	50	51.92	2.11	0.16	92.42

Table A.20

Percentage removal of treated wastewater by PACC at 150 ppm

No.	SS			COD (Cr)		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	43.00	6.00	86.05	342	85	75.15
2	75.00	4.00	94.67	671	80	88.08
3	49.00	5.00	89.80	488	88	81.97
4	32.00	5.00	84.38	583	73	87.48
5	56.00	5.00	91.07	492	72	85.37
6	32.00	3.00	90.63	377	93	75.33
7	27.00	5.00	81.48	294	85	71.09
8	33.00	6.00	81.82	264	81	69.32
9	41.00	3.00	92.68	366	71	80.60
10	73.00	4.00	94.52	437	90	79.41
11	55.00	6.00	89.09	516	80	84.50
12	59.00	6.00	89.83	472	73	84.53

No.	BOD			Zinc		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	103	23	77.67	2.83	0.11	96.11
2	94	20	78.72	2.04	0.13	93.63
3	116	19	83.62	2.15	0.11	94.88
4	183	30	83.61	1.94	0.08	95.88
5	154	39	74.68	2.66	0.09	96.62
6	182	55	69.78	1.83	0.14	92.35
7	112	47	58.04	1.88	0.12	93.62
8	93	46	50.54	2.04	0.06	97.06
9	85	50	41.18	2.07	0.10	95.17
10	122	35	71.31	1.92	0.12	93.75

No.	SS		%Removal	COD (Cr)		%Removal
	Initial	Residual		Initial	Residual	
11	138	58	57.97	2.05	0.05	97.56
12	104	34	67.31	2.11	0.05	97.63

Table A.21

Percentage removal of treated wastewater by PACC at 100 ppm

No.	SS		%Removal	COD (Cr)		%Removal
	Initial	Residual		Initial	Residual	
1	43.00	7.00	83.72	342	81	76.32
2	75.00	4.00	94.67	671	77	88.52
3	49.00	5.00	89.80	488	92	81.15
4	32.00	3.00	90.63	583	83	85.76
5	56.00	5.00	91.07	492	88	82.11
6	32.00	5.00	84.38	377	81	78.51
7	27.00	6.00	77.78	294	84	71.43
8	33.00	4.00	87.88	264	70	73.48
9	41.00	5.00	87.80	366	65	82.24
10	73.00	4.00	94.52	437	71	83.75
11	55.00	7.00	87.27	516	78	84.88
12	59.00	5.00	91.53	472	83	82.42

No.	BOD		%Removal	Zinc		%Removal
	Initial	Residual		Initial	Residual	
1	103	18	82.52	2.83	0.09	96.82
2	94	14	85.11	2.04	0.06	97.06
3	116	25	78.45	2.15	0.07	96.74
4	183	32	82.51	1.94	0.09	95.36
5	154	36	76.62	2.66	0.11	95.86
6	182	44	75.82	1.83	0.19	89.62

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No.	SS			COD (Cr)		
	Initial	Residual	%Removal	Initial	Residual	%Removal
7	112	40	64.29	1.88	0.16	91.49
8	93	40	56.99	2.04	0.08	96.08
9	85	31	63.53	2.07	0.11	94.69
10	122	43	64.75	1.92	0.15	92.19
11	138	50	63.77	2.05	0.07	96.59
12	104	29	72.12	2.11	0.09	95.73

Table A.22

Percentage removal of treated wastewater by PACC at 50 ppm

No.	SS			COD (Cr)		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	43.00	11.00	74.42	342	90	73.68
2	75.00	14.00	81.33	671	82	87.78
3	49.00	12.00	75.51	488	91	81.35
4	32.00	8.00	75.00	583	73	87.48
5	56.00	9.00	83.93	492	77	84.35
6	32.00	10.00	68.75	377	83	77.98
7	27.00	13.00	51.85	294	79	73.13
8	33.00	8.00	75.76	264	84	68.18
9	41.00	5.00	87.80	366	70	80.87
10	73.00	6.00	91.78	437	75	82.84
11	55.00	8.00	85.45	516	88	82.95
12	59.00	9.00	84.75	472	74	84.32

No.	BOD			Zinc		
	Initial	Residual	%Removal	Initial	Residual	%Removal
1	103	25	75.73	2.83	0.12	95.76
2	94	26	72.34	2.04	0.07	96.57

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No.	SS		%Removal	COD (Cr)		%Removal
	Initial	Residual		Initial	Residual	
3	116	29	75.00	2.15	0.06	97.21
4	183	36	80.33	1.94	0.10	94.85
5	154	62	59.74	2.66	0.13	95.11
6	182	49	73.08	1.83	0.08	95.63
7	112	56	50.00	1.88	0.11	94.15
8	93	38	59.14	2.04	0.07	96.57
9	85	45	47.06	2.07	0.15	92.75
10	122	43	64.75	1.92	0.11	94.27
11	138	37	73.19	2.05	0.16	92.20
12	104	42	59.62	2.11	0.13	93.84

A.5 Data Analysis of Plant-Scale Trial

Table A.23

Standard of treated wastewater

Measurement	IEAT standard	MMTh standard
pH	5.5-9.0	6.0-8.0
SS	200	100
COD (Cr)	750	375
BOD	500	250

Table A.24

Parameter of untreated wastewater at v-notch tank of line 1

No.	pH	SS	COD (Cr)	BOD	Zinc
1	7.77	<2.5	707	188	2.11
2	9.48	200.00	972	215	7.25
3	8.69	155.00	852	198	5.24
4	7.52	162.00	755	186	4.35
5	8.23	134.00	902	203	3.65
6	8.02	86.00	306	55	4.02
7	7.36	95.00	455	105	3.37

No.	pH	SS	COD (Cr)	BOD	Zinc
8	7.66	105.00	612	155	2.15
9	7.32	113.00	508	143	3.08
10	7.95	168.00	633	195	2.36
11	8.16	210.00	684	182	5.66
12	7.74	142.00	531	85	4.25

Table A.25

Parameter of untreated wastewater at v-notch tank of line 2

No.	pH	SS	COD (Cr)	BOD	Zinc
1	6.56	26.00	159	11	6.33
2	7.03	33.00	204	82	2.31
3	7.62	52.00	188	73	4.11
4	10.06	171.00	412	153	0.25
5	9.85	124.00	752	174	0.36
6	9.63	101.00	215	23	0.42
7	10.05	81.00	322	101	0.27
8	9.57	103.00	365	123	0.15
9	9.84	131.00	247	151	0.35
10	10.32	126.00	284	184	0.66
11	10.14	175.00	293	153	0.41
12	9.75	138.00	227	92	0.35

Table A.26

Parameter of treated wastewater at sedimentation tank no.1

No.	pH	SS	COD (Cr)	BOD	Zinc
1	10.37	75.00	550	66	0.15
2	10.65	194.00	536	126	0.33
3	8.69	155.00	852	198	5.24
4	7.23	62.00	165	66	5.12.

No.	pH	SS	COD (Cr)	BOD	Zinc
5	7.04	35.00	147	84	4.36
6	7.15	84.00	143	52	3.62
7	7.60	29.00	128	74	3.05
8	7.38	37.00	136	77	2.11
9	7.82	36.00	115	63	4.07
10	7.91	42.00	124	58	5.36
11	8.01	48.00	164	96	3.04
12	7.58	53.00	152	64	2.54

Table A.27

Parameter of treated wastewater at sedimentation tank no.3

No.	pH	SS	COD (Cr)	BOD	Zinc
1	9.62	4.00	78	6	0.08
2	9.84	5.00	52	5	0.05
3	9.63	3.00	61	5	0.05
4	9.85	10.00	55	6	0.09
5	10.25	8.00	84	4	0.07
6	9.63	5.00	75	5	0.10
7	9.86	5.00	62	10	0.05
8	9.74	6.00	94	8	0.06
9	9.93	4.00	83	5	0.06
10	10.05	8.00	67	9	0.08
11	9.95	6.00	53	8	0.04
12	9.86	6.00	47	8	0.03

Table A.28

Parameter of treated wastewater at inspection pit

No.	pH	SS	COD (Cr)	BOD	Zinc
1	7.62	7.00	128	9	0.11
2	7.54	8.00	136	5	0.08
3	7.58	5.00	105	8	0.10
4	7.63	10.00	88	5	0.05
5	7.51	5.00	56	7	0.04
6	7.64	6.00	104	7	0.06
7	7.58	4.00	106	6	0.04
8	7.36	11.00	86	4	0.07
9	7.53	8.00	92	8	0.08
10	7.45	12.00	85	8	0.05
11	7.51	8.00	76	6	0.04
12	7.55	5.00	64	4	0.04

APPENDIX B

CHEMICAL CONSUMPTION

Table B.1

Chemical consumption in cycle year 2015 (Existing chemical treatment program)

Month	Sulfuric acid 20%	Sodium hydroxide 50%	Calcium hydroxide	Ferric chloride 46%
January	17,700.00	3,950.00	6,540.00	5,300.00
February	21,500.00	3,450.00	6,130.00	4,600.00
March	17,700.00	3,500.00	6,035.00	4,650.00
April	18,600.00	2,900.00	4,360.00	4,100.00
May	18,600.00	3,160.00	5,000.00	4,040.00
June	16,750.00	3,000.00	5,060.00	3,620.00
Summary	110,850.00	19,960.00	33,125.00	26,310.00
July	15,100.00	3,600.00	4,400.00	3,300.00
August	19,900.00	3,900.00	6,240.00	4,300.00
September	16,100.00	4,100.00	6,600.00	4,150.00
October	13,500.00	3,850.00	6,920.00	3,650.00
November	13,900.00	3,800.00	6,645.00	4,060.00
December	17,600.00	3,550.00	4,300.00	3,250.00
Summary	96,100.00	22,800.00	35,105.00	22,710.00
Summary usage	206,950.00	42,760.00	68,230.00	49,020.00
Unit	Litre	Litre	Kg.	Litre

Month	Kurita C-3310	Kurita ZA-301S	pH adjustment	Total wastewater
January	50.00	142.00	21,650.00	40,572.00
February	53.00	128.00	24,950.00	38,600.00
March	62.00	133.00	21,200.00	38,764.00
April	44.00	73.00	21,500.00	26,727.00
May	47.00	78.00	21,760.00	27,573.00
June	47.00	70.00	19,750.00	24,941.00
Summary	303.00	624.00	130,810.00	197,177.00
July	43.00	52.00	18,700.00	20,855.00
August	55.00	83.00	23,800.00	28,356.00
September	55.00	80.00	20,200.00	27,545.00
October	60.00	60.00	17,350.00	24,029.00
November	65.00	71.00	17,700.00	26,192.00
December	44.00	34.00	21,150.00	18,569.00
Summary	322.00	380.00	118,900.00	145,546.00
Summary usage	625.00	1,004.00	249,710.00	342,723.00
Unit	Kg.	Kg.	Litre	m ³

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Table B.2

Chemical consumption in cycle year 2016 (Existing chemical treatment program)

Month	Sulfuric acid 20%	Sodium hydroxide 50%	Calcium hydroxide	Ferric chloride 46%
January	19,800.00	3,800.00	4,640.00	4,600.00
February	13,800.00	4,900.00	4,980.00	4,700.00
March	14,200.00	3,430.00	6,680.00	4,600.00
April	18,700.00	2,860.00	4,360.00	4,800.00
May	18,300.00	2,070.00	4,920.00	4,500.00
June	19,950.00	4,400.00	5,380.00	5,300.00
Summary	104,750.00	21,460.00	30,960.00	28,500.00
July	19,100.00	3,080.00	5,560.00	4,800.00
August	13,200.00	3,180.00	4,160.00	4,850.00
September	16,470.00	3,280.00	3,540.00	4,700.00
October	16,600.00	2,680.00	3,560.00	4,200.00
November	15,290.00	3,255.00	4,520.00	5,650.00
December	19,450.00	3,105.00	3,700.00	3,750.00
Summary	100,110.00	18,580.00	25,040.00	27,950.00
Summary usage	204,860.00	40,040.00	56,000.00	56,450.00
Unit	Litre	Litre	Kg.	Litre

Month	Kurita C-3310	Kurita ZA-301S	pH adjustment	Total wastewater
January	53.00	83.00	23,600.00	29,408.00
February	48.00	64.00	18,700.00	23,471.00
March	59.00	78.00	17,630.00	27,216.00
April	24.00	65.00	21,560.00	23,949.00
May	70.00	50.00	20,370.00	21,019.00
June	47.00	106.00	24,350.00	33,730.00
Summary	301.00	446.00	126,210.00	158,793.00
July	57.00	105.00	22,180.00	31,317.00
August	31.50	61.00	16,380.00	23,544.00
September	71.50	105.00	19,750.00	32,160.00
October	47.50	98.00	19,280.00	30,424.00
November	35.50	80.00	18,545.00	26,427.00
December	19.00	112.00	22,555.00	33,024.00
Summary	262.00	561.00	118,690.00	176,896.00
Summary usage	563.00	1,007.00	244,900.00	335,689.00
Unit	Kg.	Kg.	Litre	m ³

Table B.3

Chemical consumption in January-June, 2017 (Existing chemical treatment program)

Month	Sulfuric acid 20%	Sodium hydroxide 50%	Calcium hydroxide	Ferric chloride 46%
January	16,850.00	3,230.00	4,520.00	5,100.00
February	12,600.00	2,900.00	4,400.00	4,700.00
March	12,400.00	2,830.00	4,480.00	4,750.00
April	14,350.00	1,120.00	3,160.00	3,580.00
May	18,000.00	1,900.00	4,560.00	4,570.00
June	13,700.00	1,770.00	4,440.00	4,320.00
Summary usage	87,900.00	13,750.00	25,560.00	27,020.00
Unit	Litre	Litre	Kg.	Litre

Month	Kurita C-3310	Kurita ZA-301S	pH adjustment	Total wastewater
January	40.00	84.00	20,080.00	32,921.00
February	45.00	77.00	15,500.00	26,916.00
March	51.00	79.00	15,230.00	26,983.00
April	35.00	49.00	15,470.00	16,578.00
May	47.00	78.00	19,900.00	26,602.00
June	46.00	74.00	15,470.00	24,967.00
Average(1)	44.00	73.50	16,941.67	25,827.83
Summary usage	264.00	441.00	101,650.00	154,967.00
Unit	Kg.	Kg.	Litre	m ³

Table B.4

Chemical consumption in November, 2017 (New chemical treatment program)

Month	Sulfuric acid 20%	Sodium hydroxide 50%	Calcium hydroxide	Ferric chloride 46%
November	10,100.00	650.00	4,020.00	-
Summary usage	10,100.00	650.00	4,020.00	-
Unit	Litre	Litre	Kg.	Litre

Month	Kurita C-3310	COAG I-305	pH adjustment	Total wastewater
November	42.00	2,720.00	10,750.00	29,984.00
Summary usage	42.00	2,720.00	10,750.00	29,984.00
Unit	Kg.	Kg.	Litre	m ³

Table B.5

Chemical consumption cost

Year	2013	2014	2015	Unit
Sulfuric acid 20%	302,900.00	318,450.00	206,950.00	Litre
Convert	342,579.90	360,166.95	234,060.45	Kg.
Cost 5.5 Baht/Kg.	1,884,189.45	1,980,918.23	1,287,332.48	Baht
Sodium hydroxide 50%	69,550.00	80,400.00	42,760.00	Litre
Convert	105,855.10	122,368.80	65,080.72	Kg.
Cost 13.5 Baht/Kg.	1,429,043.85	1,651,978.80	878,589.72	Baht
Calcium hydroxide	94,315.00	103,705.00	68,230.00	Kg.
Cost 6.5 Baht/Kg.	613,047.50	674,082.50	443,495.00	Baht
Ferric chloride 46%	158,550.00	163,480.00	49,020.00	Litre
Convert	242,581.50	250,124.40	75,000.60	Kg.
Cost 8 Baht/Kg.	1,940,652.00	2,000,995.20	600,004.80	Baht
Kurita C-3310	668.00	701.50	625.00	Kg.
Cost 205 Baht/Kg.	136,940.00	143,807.50	128,125.00	Baht
Kurita ZA 301S	-	-	1,004.00	Kg
Cost 365 Baht/Kg.	-	-	366,460.00	Baht
COAG I-305	-	-	-	Kg.
Cost 66 Baht/Kg.	-	-	-	Baht
pH adjustment	372,450.00	398,850.00	249,710.00	Litre
Total wastewater	496,960.00	540,468.00	342,723.00	m ³
Summary cost	6,003,872.80	6,451,782.23	3,704,007.00	Baht
Treatment cost/total wastewater	12.08	11.94	10.81	Baht/m ³
Year	2016	2017	Nov'17	Unit
Sulfuric acid 20%	204,860.00	87,900.00	10,100.00	Litre
Convert	231,696.66	99,414.90	11,423.10	Kg.
Cost 5.5 Baht/Kg.	1,274,331.63	546,781.95	62,827.05	Baht
Sodium hydroxide 50%	40,040.00	13,750.00	650.00	Litre
Convert	60,940.88	20,927.50	989.30	Kg.
Cost 13.5 Baht/Kg.	822,701.88	282,521.25	13,355.55	Baht
Calcium hydroxide	56,000.00	25,560.00	4,020.00	Kg.
Cost 6.5 Baht/Kg.	364,000.00	166,140.00	26,130.00	Baht
Ferric chloride 46%	56,450.00	27,020.00	-	Litre
Convert	86,368.50	41,340.60	-	Kg.
Cost 8 Baht/Kg.	690,948.00	330,724.80	-	Baht
Kurita C-3310	563.00	264.00	42.00	Kg.
Cost 205 Baht/Kg.	115,415.00	54,120.00	8,610.00	Baht
Kurita ZA-301S	1,007.00	441.00	-	Kg
Cost 365 Baht/Kg.	367,555.00	160,965.00	-	Baht

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Year	2013	2014	2015	Unit
COAG I-305	-	-	2,720.00	Kg.
Cost 66 Baht/Kg.	-	-	179,520.00	Baht
pH adjustment	244,900.00	101,650.00	10,750.00	Litre
Total wastewater	335,689.00	154,967.00	29,984.00	m ³
Summary cost	3,634,951.51	1,541,253.00	290,442.60	Baht
Treatment cost/total wastewater	10.83	9.95	9.69	Baht/m ³



APPENDIX C SLUDGE DISPOSAL

Table C.1

Sludge disposal cost (2100 Baht/Ton) by AKKHIE PRAKARN Pub Co., Ltd (AKP)

Month	2015	Disposal cost	2016	Disposal cost
January	44,030	92,463	46,050	96,705
February	43,580	91,518	33,930	71,253
March	45,320	95,172	36,630	76,923
April	27,230	57,183	34,840	73,164
May	35,439	74,422	34,490	72,429
June	35,950	75,495	31,660	66,486
July	32,790	68,859	28,635	60,134
August	34,030	71,463	33,590	70,539
September	36,860	77,406	34,190	71,799
October	28,940	60,774	29,200	61,320
November	28,330	59,493	32,450	68,145
December	23,130	48,573	25,560	53,676
Summary	415,629	872,821	401,225	842,573
Average	34,636	72,735	33,435	70,214
Unit	Kg.	Baht	Kg.	Baht

Month	2017	Disposal cost	New program	Disposal cost
January	35,460	74,466	-	-
February	31,560	66,276	-	-
March	32,180	67,578	-	-
April	18,200	38,220	-	-
May	34,550	72,555	-	-
June	32,720	68,712	-	-
July	-	-	-	-
August	-	-	-	-
September	-	-	-	-
October	-	-	-	-
November	-	-	34,680.00	72,828.00
December	-	-	-	-
Summary	184,670	387,807	34,680.00	72,828.00
Average	30,778	64,635	34,680.00	72,828.00
Unit	Kg.	Baht	Kg.	Baht

APPENDIX D

CARBON DIOXIDE (CO₂) REDUCTION

Table D.1CO₂ conversion coefficient

Item	Coefficient	Specific gravity (SG)
Ferric chloride (46%)	0.182	1.530
Calcium hydroxide	0.169	-
Sulfuric acid (20%)	0.013	1.131
Sodium hydroxide (50%)	0.672	1.522
Kurita C-3310	2.324	-
Kurita ZA-301S	2.324	-
COAG I-305	0.317	-
Sludge waste	0.140	-
Unit	Kg-CO ₂ /Kg	-

Table D.2CO₂ emission of existing chemical treatment program

Month	Coagulant	pH adjustment	Flocculant	Sludge waste	Total CO ₂
January	2,911.11	4,306.14	116.20	6,142.19	13,475.63
February	2,614.36	3,852.61	123.17	6,079.41	12,669.55
March	2,623.85	3,846.13	144.09	6,322.14	12,936.20
April	2,048.18	3,246.42	102.26	3,798.59	9,195.44
May	2,151.25	3,512.20	109.23	4,943.74	10,716.42
June	2,025.85	3,320.60	109.23	5,015.03	10,470.70
July	1,783.37	3,908.95	99.93	4,574.21	10,366.45
August	2,444.83	4,288.37	127.82	4,747.19	11,608.20
September	2,456.93	4,435.23	127.82	5,141.97	12,161.95
October	2,325.30	4,140.26	139.44	4,037.13	10,642.13
November	2,418.56	4,095.21	151.06	3,952.04	10,616.86
December	1,710.71	3,895.72	102.26	3,226.64	8,935.33
Average	2,292.86	3,903.99	121.04	4,831.69	11,149.57
Unit	Kg.-CO ₂				

Table D.3CO₂ emission of new chemical treatment program

Month	Coagulant	pH adjustment	Flocculant	Sludge waste	Total CO ₂
November	1,541.62	799.82	97.61	4,837.86	7,276.91
Unit	Kg.-CO ₂				

APPENDIX E

CALCULATION EXAMPLES

E.1 Preparation of stock solutions

For jar testing, the factor value was found for doing the experiment in small scale. A 1% dilution was prepared by dissolve 1 gram of chemical into 99 grams of distilled water. Therefore 1 mL of 1% dilution would have 0.01 grams of the chemical. The factor was shown in Table E.1.

Example Preparation 500 mL sample

$$\frac{0.01 \text{ g}}{0.5 \text{ L}} = 0.02 \frac{\text{g}}{\text{L}} = 20 \frac{\text{mg}}{\text{L}}$$

Table E.1

Factor value for preparing the chemical solution used in jar testing

Sample (mL)	Factor
100	100
200	50
250	40
500	20
1000	10

The preparation of chemical solution volume at desired concentration was obtained using the dilution equation:

$$C_1V_1 = C_2V_2$$

Where C_1 and C_2 are the initial and final concentrations of solution, V_1 and V_2 are the initial and final volume of solution respectively

The concentration/dosage of chemical solution to use in jar testing was obtained using the following formula:

$$\text{ppm of 1 mL} = \% \text{ dilution} \times \text{factor}$$

Example Preparation 5% dilution at 100 mL of Ferric chloride 46% solution and the wastewater sample is 500 mL.

$$C_1V_1 = C_2V_2$$

$$\frac{46 \text{ mg}}{L \times V_1} = \frac{5 \text{ mg}}{L} \times 100 \text{ mL}$$

$$V_1 = \frac{500}{46} \text{ mL}$$

$$V_1 = 10.87 \text{ mL}$$

So, Ferric chloride should be prepared with 11 mL then diluted in distilled water to 100 mL to obtain 5% dilution.

And

$$\begin{aligned} \text{ppm of 1 mL} &= \% \text{ dilution} \times \text{factor} \\ \text{ppm of 1 mL} &= 5 \times 20 \\ \text{ppm of 1 mL} &= 100 \text{ ppm} \end{aligned}$$

Therefore, 1 mL of Ferric chloride 5% dilution was 100 ppm for jar testing at 500 mL of wastewater sample.

E.2 Percentage removal

Percentage of removal for SS, COD (Cr), BOD and heavy metal (Zn) level was obtained using the following formula:

$$\text{Removal (\%)} = [(C_i - C_f) / C_i] \times 100$$

Where C_i and C_f are the initial and final concentrations for each parameter of automotive wastewater respectively.

Example The untreated wastewater has SS equal to 44 ppm and after treatment the treated wastewater has SS equal to 6 ppm.

$$\text{Removal (\%)} = \left[\frac{(C_i - C_f)}{C_i} \right] \times 100$$

$$\text{Removal (\%)} = \left[\frac{(44 - 6)}{44} \right] \times 100$$

$$\text{Removal (\%)} = 86.36$$

E.3 Plant-scale trial

The feed rate of PACC coagulant in plant-scale trial was obtained using the following formula:

$$\text{Feed rate}_{\text{coagulant}}(Q) = \frac{\text{Flow rate}_{\text{wastewater}}(\dot{V}) \times \text{Dosage}_{\text{coagulant}}}{10 \times (\% \text{ dilution}_{\text{coagulant}})}$$

Table E.2

Feed rate of coagulant in plant-scale trial

Line	Flow rate	Dosage	% dilution	Feed rate	
1	25.00	100.00	100.00	2.50	41.67
2	40.00	100.00	100.00	4.00	66.67
Unit	m ³ /hr.	ppm	-	L/hr.	mL/min



BIOGRAPHY

Name: Mr. Jirat Greesaeng

Date of Birth: September 2, 1995

Address: 147/1 Village No.5 Boonyanusat Road, Nong Ngoo Leuam Sub-district,
Muang District, Nakhon Pathom 73000

E-mail: jirat.greesaeng@gmail.com

Academic Background:

- 2008-2013: High School
Phraphathom Witthayalai School, Nakhon Pathom
- 2014-Present: Petrochemical Engineering (B.Eng.)
Department of Chemical Engineering, Faculty of Engineering,
King Mongkut's Institute of Technology Ladkrabang, Bangkok

Working Experiences:

- June-July 2017: Internship Program 2017
United Winery and Distillery Co., Ltd.
- August-November 2017: Cooperative Education 2017
Mitsubishi Motors (Thailand) Co., Ltd.