INFLUENCE OF CHLORINE CONCENTRATION ON THE EFFECTIVENESS OF CLEANING-IN-PLACE AGENTS

THESIS

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ABSTRACT

The effectiveness of cleaning agents for in-place cleaning of food-contact surfaces in food manufacturing facilities continues to be a topic of interest. Sodium hydroxide is used to remove the organic matter attached on a food surface. Sodium hypochlorite is a common additive used in conjunction with sodium hydroxide in cleaning solutions. Although sodium hypochlorite is added to improve the effectiveness of the cleaning, sodium hypochlorite is viewed as potentially harmful to the environment. The overall objective of this investigation was to reduce the environmental impact of sodium hydroxide-based cleaning solutions through minimization of sodium hypochlorite usage while ensuring no loss in cleaning efficacy.

A deposit of 20%-w/w of non-fat dry milk solution was placed on the surface of coupons made of stainless steel 316 and held at 75°C for one hour. The coupons were then cleaned with different concentrations of cleaning solution comprised of NaOH, sodium hypochlorite, and water in a temperature-controlled container with an agitator to provide the shear force that would remove the protein film. Cleaning efficiency was monitored by a decrease in the fraction of residual film (RF) at different time points. The RF's at specified time points were modeled with first-order kinetic models. A rate constant (k) was obtained from this model and used for the parameter of cleaning solution efficiency. A 5-by-5 full factorial design was used to evaluate the effectiveness of sodium hypochlorite, sodium hydroxide, and their interactions during cleaning.

With the dry mass difference method as explained before, sodium hydroxide concentration was shown to be significant (p-value < 0.0001) factor for cleaning. The cleaning rate increased with an increase in sodium hydroxide concentration and reached a maximum between 5 to 15 kg/m^3. At concentrations above 15 kg/m^3, the cleaning rates decreased with increase in concentration. The cleaning rate was not influenced by sodium hypochlorite concentration over the range from 0 to 300 ppm at $\alpha = 0.05$. The interaction between NaOH and sodium hypochlorite was also found to be not significant at $\alpha = 0.05$. Sodium hydroxide concentration was found to be the only significant factor with influence on cleaning rate, and the analysis concluded that the highest cleaning rate at a sodium hydroxide concentration of 8.48 kg/m^3.

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FIELD OF STUDY

Major Field: Food Science and Technology

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INTRODUCTION

Sodium hypochlorite has been widely used in cleaning and sanitation purpose in textile, water treatment, and food industry. Sodium hypochlorite by itself is considered a highly-toxic chemical (Ozturk et al., 2016). The residual of the sodium hypochlorite treatment may get in contact with soil or groundwater and create Trihalomethane (THM), such as chloroform. THM is considered carcinogenic and can create both skin and health problems (Jackman & Hughes, 2010).

In 2050, it is predicted that the population of the world will increase to 9 billion people (Floros et al., 2010). To ensure food security and food safety, thermal preservation has been the most common technique for more than fifty years (Craven et al., 2008; Sepulveda et al., 2009). However, thermal preservation leads to the formation of undesirable deposits on manufacturing equipment, which is widely called fouling (Boxler et al., 2013).

How fouling happens and what caused it have been studied extensively (Fryer et al., 2006; Jimenez et al., 2013; Lelieveld et al., 2005). Fouling in food manufacturing causes heat transfer inefficiency and increase the friction loss due to reduction in the cross-sectional area of food equipment, and thus, increasing the energy consumption (C.R.Gillham et al., 1999). Furthermore, in food products, fouling leads to more severe problems such as product cross-contamination and creates a suitable environment for microorganisms to grow. Therefore, frequent cleaning of food processing equipment should be conducted to mitigate these potential dangers (Jimenez et al., 2013). Cleaning effectiveness and efficiency depends on understanding fouling from the deposit formation to the factors influencing the removal of the deposits.

Even though cleaning is essential to maintaining food safety and quality, it leads to downtime in production and additional cost due to chemical waste treatment and additional energy consumption (Bansal & Chen, 2006; Deka & Datta, 2017; Rad & Lewis, 2014; Sharp, 1985; Singh et al., 2019). According to Rad and Lewis (2014), cleaning in a milk process facility takes up to 34% of the water usage as represented in Figure 1.1. The energy cost during cleaning takes up to 14% for a milk plant and 9% for an integrated powder, cheese and whey plant.

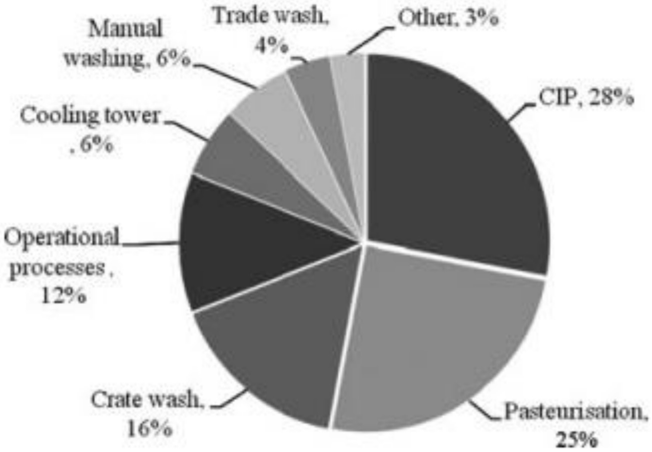

Figure 1.1. Breakdown of water use in milk processing facility (Rad & Lewis, 2014).

In the 1950s, computerized and automation technology allowed development in food industry through the implementation of cleaning-in-place (CIP) (Davey et al., 2015). Prior to the introduction of cleaning-in-place, cleaning food contact surface could only be done manually. Cleaning-in-place system offers a more repeatable, controlled, efficient, and safer operation compared to manual cleaning, in exchange to higher capital expense due to the automation

(Thomas & Sathian, 2014). The advantages of CIP system outweigh the drawbacks, and lead to the food industries to show a major shift to this system over the past 10 to 15 years.

Past researchers have identified 4 factors that affect cleaning: mechanical action, chemical action, temperature and time (Lelieveld et al., 2005). The impact of temperature on cleaning has been studied extensively. Temperatures above 45°C improved the efficiency of deposit removal in pre-rinse step (Fan, 2018). The effect of temperature on cleaning also depends on the type of food deposits (Goode et al., 2013). Mechanical action is the physical force required to shear and lift the deposit from the surface. It is usually represented in terms of wall shear stress. Many studies about the effect of mechanical action on cleaning focus on the use of pulsed flow (Gillham et al., 2000; Yang et al., 2019), the effect of shear stress by manipulating the velocity of the flow (Fan et al., 2015), and impact cleaning with liquid jets (Glover et al., 2016; D. I. Wilson et al., 2014, 2015).

The use of proper chemicals is important as cleaning starts with the interaction between the active agents in cleaning chemicals with the deposit (Fryer et al., 2006). The excessive usage of chemicals in cleaning picks up more problem as the effluent usually contains compounds that are not environmentally friendly. Several approaches to reduce the usage of chemicals have been explored. Enzyme has been studied to have a comparable efficacy to sodium hydroxide, in addition to have a more sustainable effluent (Chutrakul et al., 2019; Guerrero-Navarro et al., 2019). Applying enzyme cleaning presents challenges at manufacturing plants as the industrial dosage, process control, and its cost would need to be considered (Goode et al., 2013). Reusing chemical cleaning agents has been explored (Danalewich et al., 1998; Trägårdh & Johansson, 1998), although purification might require additional capital investment when applied to the food industries. A more appropriate solution would be to reduce the usage of chemicals through the optimization of the concentration of the active agents.

While sodium hypochlorite has a potential harm to the environment, its influence in food contact surface cleaning has not yet been studied sufficiently. The overall goal of this research is to explore the effect of sodium hypochlorite concentration on the cleaning efficiency and its interaction with sodium hydroxide during the alkali washing step. The objectives of this research are to:

1. Investigate the influence of sodium hydroxide concentration on the effectiveness of removing product residues from food-contact surfaces during CIP.
2. Determine the contribution of sodium hypochlorite concentration on the effectiveness of sodium hydroxide in removal product residues during CIP.
3. Develop recommendations on the optimum concentration of cleaning agents for effective removal of product residues during CIP.

LITERATURE REVIEW

2.1. Fouling

Fouling is considered as an adverse phenomenon of deposited material on the surface which can influence the overall resistance of the heat flow (Bott & Melo, 1997). This deposit formation that is usually made of insulating material will reduce the heating efficiency of the heating instrument (Jimenez et al., 2013). Fouling is a big problem in filtration or heat exchange system as this will cause inefficiency in hydraulic and heat transfer (Bansal & Chen, 2006; Guo et al., 2012; Jimenez et al., 2013; Tijing et al., 2015; Watkinson & Wilson, 1997). In bioreactor process, fouling is caused by exopolymers produced during lysis of bacteria (Bouhabila et al., 2001).

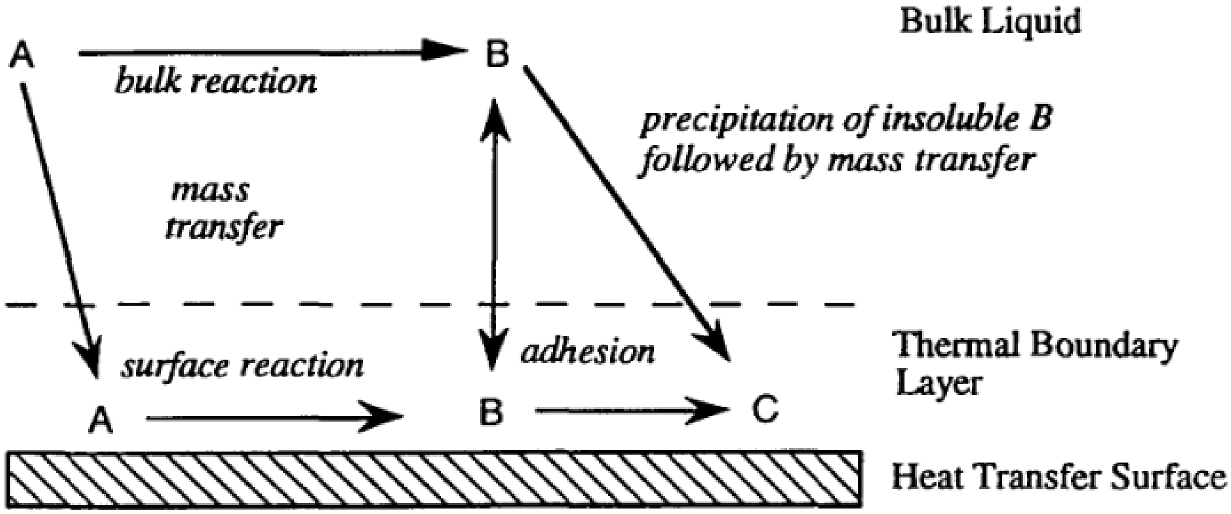

Figure 2.1 Step of chemical reaction fouling mechanism (Watkinson & Wilson, 1997)

The foulant material is usually insoluble and comes from a reaction whose reactant and product are soluble (Watkinson & Wilson, 1997). The characteristics of fouling will vary depending on the process and material. For example, membrane systems in waste water treatment process were fouled with organic (protein, small hydrophobic acid, humic and fulvic acids) and inorganic material (calcium carbonate, barium sulfate, silica, calcium phosphate), colloid and cake layers (silt, clay, precipitated crystal), and biofouling (Guo et al., 2012).

Organic fouling was a lot to be found in waste water treatment and food / beverage system due to the composition of the material (Fryer et al., 2006; W. J. Kim et al., 2018; Mi & Elimelech, 2010; S. H. Park et al., 2018; Porcelli & Judd, 2010). Inorganic material was also found in membrane and many food processing systems. Different processing might result in different composition of organic and inorganic fouling (Burton, 1968). Colloid and cake layers were commonly found in filtration system such as reverse osmosis membrane, nanofiltration, ultrafiltration, etc. (Boo et al., 2012; Costa et al., 2006; C. Park et al., 2008). Biofouling or biofilm is also common in a system with heavy organic fouling. It is caused by build-up of microorganisms that produce extracellular polysaccharides (EPS) and it makes it harder to remove (J. S. Baker & Dudley, 1998; Flemming & Wingender, 2010; Wirtanen & Salo, 2003).

In membrane system, higher fouling load will impact on declining membrane fluxes, increasing pressure needs, and increasing permeate conductivity (Penña et al., 2013). In some cases, replacement might also be necessary and this will increase operating cost (Chang et al., 2002). When used for wastewater treatment, the membrane fouling usually consists of membrane material and activated sludge liquor (substrate components, cells, cell debris, and microbial metabolites) (Chang et al., 2002).

Fouling in heat exchanger system will also create severe negative impact on manufacturing process: production loss due to efficiency loss, high maintenance cost, higher consumption of water, higher safety and environmental hazard during operation and cleaning (Müller-Steinhagen et al., 2009). The impact of fouling on a unitary air-conditioning system also showed increased pressure drop and reduced heat exchange performance compared to the clean condition (Pak et al., 2003).

Other than hydraulics and heat transfer inefficiency, fouling layer may affect food safety and quality as well (Jimenez et al., 2013). Attached product on the processing surface from the prior batch might contaminate the current batch. The presence of uncleaned fouling layer might also provide nutrition to the growth of unwanted microorganisms.

2.2. Milk Fouling

Depending on the source of the milk, milk may have different compositions as shown in Table 2.1 (Pereira, 2014). The difference in composition might create different characteristics in fouling. Mineral and beta-lactoglobulin (contained in whey protein from milk) are important in the induction step of fouling (Jimenez et al., 2013). Fat was shown to be not having any impacts for fouling (Visser & Jeurnink, 1997). Casein in milk is already in a denatured state, so it does not take part in the induction period, but more during the growth phase (Jimenez et al., 2013).

Table 2.1 Average composition of goat, sheep, cow, and human milk (Pereira, 2014)

Parameters	**Goat**	**Sheep**	**Cow**	**Human**
Fat (%)	3.8	7.9	3.6	4.0
Lactose (%)	4.1	4.9	4.7	6.9
Protein (%)	3.4	6.2	3.2	1.2
Energy (kcal / 100 mL)	70	105	69	68
Calcium (mg / 100 g)	134	193	122	33
Phosphorus (mg / 100 g)	121	158	119	43
Vitamin A (IU)	185	146	126	190
Vitamin D (IU)	2.3	0.18 (µg)	2.0	1.4

The process of the milk will also generate different characteristics of fouling. As explained by Burton (Burton, 1968), there are two types of protein fouling caused by different processing temperature: type A fouling and type B fouling. The deposits represented in these types have different characteristics. Type A deposit has soft texture, similar to curd, and is white or cream in color. It contains mostly protein (50-60%), and also 30-35% of mineral matter and about 4-8% of fat. Type B deposit has brittle structure and is grey in color. It contains about 70% of ash content, around 15-20% of protein and similar fat content to type A deposit.

There have been many different arguments on the steps of fouling development. Jimenez et al. (2013) explained that mineral contents was very significant in the initial phase of deposit formation, or induction period. The layer of denatured protein was the first substance to be formed during fouling formation. However, when the presence of mineral content was minimum, the growth of the deposit was very small. Foster and Green (1990) showed that the inner layer of the surface contains more mineral more than proteins, while the outer layer was the opposite. Layer with higher concentration of protein was shown to be easier to remove. They also explained the way that higher temperature fouling would create fouling with higher concentration of salt due to insolubility of salt in higher temperature process. And since the protein layer was diffuse and irregular, it was possible that salts could pass through it. This statement was the opposite to Fryer (1989) and Jimenez et al. (2013).

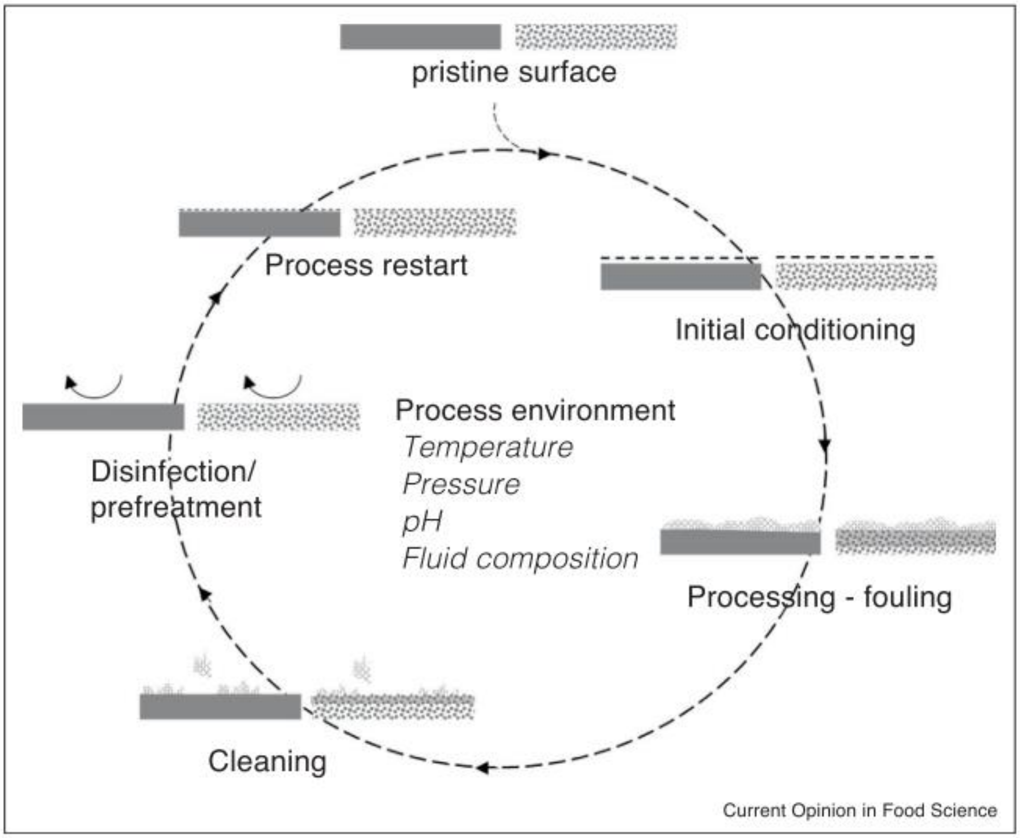

Figure 2.2 Stages of fouling and cleaning cycle (D. Ian Wilson, 2018)

Because of many adversities caused by fouling, many researches had been done to minimize the material deposition. The mitigation can be done in two ways: surface modification and processing alterations (Kylee R Goode et al., 2013). Zouaghi et al. (2018) showed that PEO-sillicone coating material could reduce dairy based fouling significantly in pasteurizing process. It could also resist the attachment of foodborne pathogenic bacteria. Textured surface (relatively higher roughness) was shown to also have higher amount of deposits. Fluorosilanized mirror-like surface was shown to have least deposit compared to native stainless steel (Zouaghi, Six, et al., 2018). Techniques and studies had been explored as well to create a self-cleaning coating on the surface by using ultra-hydrophobic surface (Ganesh et al., 2011).

As previously mentioned, fouling might have different characteristics depending on the process temperature that the passing material went through (Burton, 1968). Different raw material composition might also affect the difference in deposit characteristics (Jimenez et al., 2013; Visser & Jeurnink, 1997). Plate heat exchanger is mostly used in dairy industry because it has a good heat transfer and compact space, but different types of heat exchangers are also getting more common to be used because it can create less deposit (Bansal & Chen, 2006).

2.3. Cleaning

Cleaning is understood as physically or chemically removing unwanted material from surface as the maintenance of equipment (Fan, n.d.). There are many aspects affecting cleaning: temperature, velocity, cleaning agent (Fan, n.d.; Trinh et al., 2017).

Understanding cleaning requires the knowledge of the fouling itself. There are three phases in cleaning process: the deposit, the surface, and also the cleaning solution (Fryer et al., 2006). Between the deposit and the cleaning solution phase, mechanical force and mass transfer (such as wetting, dissolution, or swelling) are the important parameter. Adhesive force between deposit and the surface needs to be overcome when deposit is to be removed from the surface (Fan, n.d.).

Fouling removal during CIP process relies on the chemical reaction / modification and hydraulic action of the cleaning solution circulated within the system. The chemical reaction may cause swelling of the fouling, dissolution, and ageing, while the hydraulic action provides the energy to lift, scour, erode and remove the deposit by mass transfer (Gillham et al., 1999).

2.3.1. Cleaning-in-Place process

Cleaning-in-place (CIP) practice had been reported in a publication from 1950s (Stewart & Seiberling, 1996; Tamime, 2008). CIP process is a cleaning process that has an objective to clean the food processing equipment without dismantling the processing equipment, and thus, reduce the overall cleaning time (or downtime). It involves jetting or spraying on food contact surfaces or circulating cleaning solutions with increased velocity and turbulence (Thomas & Sathian, 2014). In many food process facilities, this process is done daily to ensure the quality and safety of the product (Kylee R Goode et al., 2013). Optimizing the factors behind this process becomes very important since it can significantly increase the production time, reduce the water usage and waste treatment cost (C.R.Gillham et al., 1999; Jimenez et al., 2013; Caroline Lelièvre et al., 2002).

2.3.2. Factors in CIP

In industrial practice, the factors affecting cleaning can be represented in Sinner's cycle: time, temperature, chemical action, and mechanical action (Kylee R Goode et al., 2013; Hagsten et al., 2019; Lelieveld et al., 2005). Changing one parameter of the circle requires some adjustment to the other parameters. These factors are then adapted to each application depending on their process and their condition.

Cleaning time is closely related to the kinetics of the fouling removal. There have been many researches done to model kinetics of cleaning in different types of foulant. *Bacillus cereus* had been used as an indicator organism to show the cleanliness of a system (C. Lelièvre et al., 2002). In this paper, *Bacillus cereus* removal could be represented with simple 1st order model kinetics. Wall shear stress played an important part in the removal of the microorganism. Image processing had also been used by researchers to determine the cleanliness of the system (Dürr, 2002; Phinney, 2019). Dürr (2002) would further use the result from the image analysis and modelled the kinetics with Weibull model.

Wall shear stress and Reynolds number are the parameters mostly used to represent mechanical action in cleaning. The higher the velocity of cleaning fluid interfacing with the deposit, the higher the wall shear stress will be (C.R.Gillham et al., 1999; Fan, 2018). This resulted in lower cleaning time. From Fan (2018), it was shown that although the Reynolds number was higher by 5 times, the efficiency in cleaning only improved by 10%. Pulsed flow during cleaning was shown to be more effective in removing egg yolk deposits on tank wall surface and on plate heat exchanger with protein deposits (Fryer et al., 2006; Yang et al., 2019).

The effect of temperature in cleaning had been studied for quite a long time. Higher temperature would result in higher cleaning rates (C.R.Gillham et al., 1999; Fryer et al., 2006). Gillham (1999) also suggested that the deposit removal rate would be most sensitive to temperature than hydraulic mass transport (mechanical action). Fan (2018) studied the impact of temperature and time to the removal of the deposit during the first rinse step of cleaning-in-place. The result showed that higher temperature would have faster deposit removal, although further higher temperature would probably not give the same significant impact as it was during lower temperature.

Chemical action will affect the fouling by swelling the deposit, dissolve, or age and change the composition and structure of the deposit over time (C.R.Gillham et al., 1999). The presence of additives in the cleaning solution could also enhance the soil penetration, reducing the surface tension, and descaling depending on the type of the deposits (Taylour & Rosner, 2016). Although it makes more sense to have higher cleaning efficiency with higher concentration, that is not always the case. Timperley and Smeulders (1988) had shown that if the concentration of alkali was too high, would take longer to clean the deposit from heat exchangers instead. Fan (2018) had also indicated that higher concentration of alkali would clean better until certain concentration, and the efficiency might decline if it got higher. Higher concentration was also shown to not have higher cleaning efficiency in cleaning egg yolk deposit on tank wall surface (Yang et al., 2019). Fryer et al. (2006) also indicated that although the existence of optimum point in chemical cleaning were not yet found, the data showed that increasing the chemical concentration would not always help cleaning efficiency.

Alkaline cleaners are mostly used for cleaning organic matters. This type of solution can reinforce swelling phase of the deposit and, with the shear stress from the flow, the deposit will be easier to be cleaned. Inorganic matters are mostly cleaned with acid cleaners. Acid chemicals are also used to help removing traces of alkaline left in the equipment surfaces (Bremer et al., 2006; Chisti, 1999; Fryer et al., 2006).

Enzyme has also been a promising alternative for cleaning solution (Fryer et al., 2006). Chutrakul et al. (2019) showed that enzyme cleaning in addition to the previously surfactant cleaning can achieve similar deposit removal as using sodium hydroxide. Paul et al. (2014) showed biodegradable enzyme at higher temperature could perform cleaning as good as conventional CIP agents, and more environmentally favorable. Cleaning with enzyme was also observed to be causing reduction in water and temperature usage, and shorter cleaning times (Guerrero-Navarro et al., 2019).

2.3.3. Additives in chemical

Studies had been done to understand the impact of additives in chemical cleaning agents (Bremer et al., 2006; Chisti, 1999). Bremer (2006) suggested that addition of certain additive containing chelating, sequestering agents, and surfactants can improve the performance in removing biofilm. This study also showed that the caustic additive was effective when blended with sodium hydroxide, and less efficient when used by itself. EDTA had been used a lot as an additive in alkaline cleaning agents due to its ability to compensate water hardness and even sequester calcium phosphate, a salt compound found in milk (Dürr & Graßhoff, 1999).

Sodium hypochlorite had also been commonly added to alkaline cleaning agents with the purpose of increasing its efficiency. One earliest documentation found to record this activity experimented with sodium hypochlorite added to 3 different commercial alkaline cleaning agents (MacGregor et al., 1954). The concentration range of sodium hypochlorite said to be improving the cleaning efficiency was 25 to 100 ppm. Fukuzaki (2006) mentioned that sodium hypochlorite was considered to have an excellent cleaning action, in addition to its role as disinfectant. Timmerman (2011) mentioned that the industry usually added chlorine up to 200 ppm during alkaline cleaning step to improve its efficiency.

MATERIALS AND METHODS

3.1. Stainless-steel surface preparation

Stainless-steel surface was chosen in this study because even though it is widely used especially in dairy processing equipment, stainless-steel is prone to fouling because of the high-surface energy and hydrophilic nature. There are 2 types of stainless-steel finish commonly used in food industry: 304 and 316. Stainless-steel 304 and 316 were shown to have no difference in protein attachment, but might have different attachment to viable cells (Barish & Goddard, 2013; Jullien et al., 2003; Karlsson et al., 1998; W. Kim et al., 2019).

Stainless-steel 316 finish coupons (2.4 cm by 2.4 cm) were used for this study. The coupons surface was polished to minimize variability of foulant attachment due to the surface roughness (Barish & Goddard, 2013; Changani et al., 1997; Jullien et al., 2003). The coupons were polished with sandpaper (3M Sandblaster Pro, St. Paul, MN 55144-1000) gradually from 220, 300, and 600 grit in advance of the study.

Before each experiment, four stainless-steel coupons were soaked with 2%-w/w of formulated chlorinated-alkaline liquid detergent (Principal, Ecolab, St. Paul, Minnesota USA 55102) in water overnight to loosen any organic material attached on the coupon. The coupons were rinsed with water, soaked in caustic solution, and then manually cleaned to remove remaining organic deposits. This step was then repeated with formulated acid solution (HD PL-10 Plus, Ecolab, St. Paul, Minnesota USA 55102). The acid step was completed to dissolve inorganic matter attached to the stainless-steel surface. Subsequently, the coupons were rinsed with water and cleaned with 50:50 mixture of hexane (Fisher Scientific, Pittsburgh, PA) and ethanol (Decon

Laboratories, King of Prussia, PA 19406) to ensure that there was no chemical residue left on the surface. Lastly, the coupons were rinsed with de-ionized reverse osmosis (DI-RO) water, before being air-dried overnight.

3.2. Surface fouling methods

Several methods had been studied to create consistent and measurable fouling material on stainless steel surface. Non-fat dry milk (Monarch, US Foodservice Inc., Rosemont, IL 60018) was used for these studies, as fat would not affect significantly to the fouling (Visser & Jeurnink, 1997). The method of stainless-steel surface fouling referred to Fan (2018).

Twenty (20) grams of milk (powder) was firstly mixed with 80 grams of water. After being mixed for at least 15 minutes, the solution was stored in 4^{o}C refrigerator overnight to ensure hydration. Six hundred (600) mL of this solution was then pipetted onto stainless-steel coupon surface and spread carefully with plastic pipette tips to cover the whole surface area. The spreading step was very important because different area caused by the milk droplet would create a great variability to the characteristics of the foulant and affect the consistency during cleaning. The stainless-steel coupon covered with milk solution was then heated and dried an oven at 70-80^{o}C for one hour. This step removed most of the water on the solution and created cooked milk fouling layer on the stainless-steel coupon.

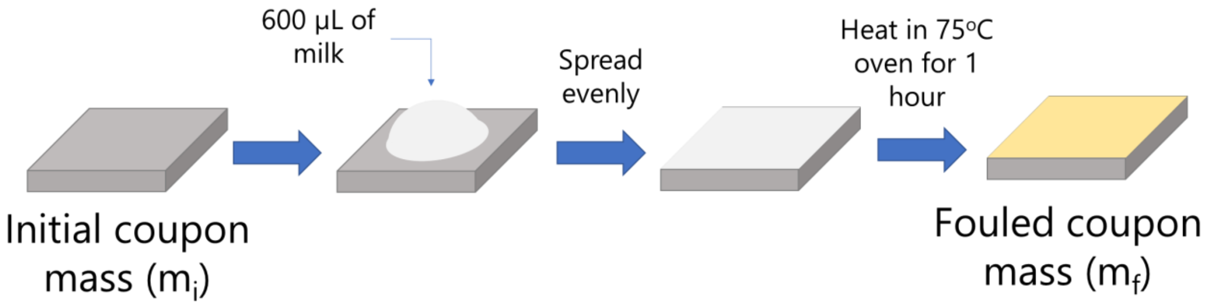

Figure 3.1. Steps on preparing protein deposit.

3.3. Measurement methods

To capture the amount of milk fouling layer at certain time, dry mass change between each step was assessed with analytical balance with repeatability up to 0.4 mg (Mettler Toledo ME54E, Mettler-Toledo, LLC, Columbus OH 43240). Dry mass change had been used in many references as a method to detect the presence of fouling on a surface (Guerrero-Navarro et al., 2019; Khaldi et al., 2018; Trinh et al., 2017) as it can quantitatively measure the amount of fouling layer on the surface.

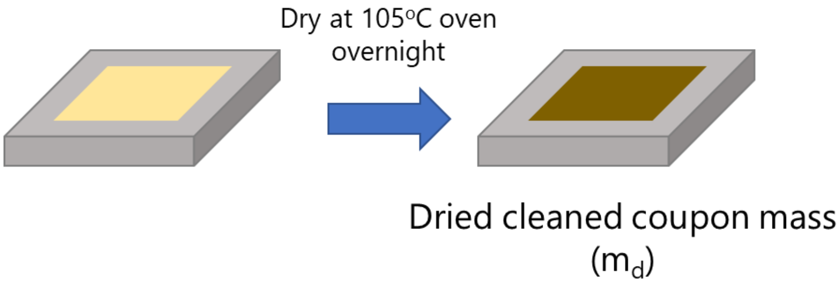

Figure 3.2. Steps on drying fouling remains after cleaning.

Residual film could be calculated with following formula.

$$Residual\ film\ (\frac{m}{m_0}) = \frac{Mass\ after\ cleaning\ (m_d) - Coupon\ mass\ (m_i)}{Mass\ after\ fouling\ (m_f) - Coupon\ mass\ (m_i)} \quad (1)$$

3.4. Cleaning solutions development

Cleaning samples were created by mixing DI-RO water, 10-15% sodium hypochlorite solution (Sigma-Aldrich, St. Louis MO 63103), and 40%-w/v sodium hydroxide solution (Ricca Arlington TX 76012). Sodium hypochlorite in industrial application was usually added up to 200 ppm to improve the cleaning ability of the caustic solution (Timmerman, 2011).

Sodium hypochlorite solution was diluted one-log first before being mixed to make cleaning solution samples so the initial concentration of sodium hypochlorite could be determined by iodometric method (Jeffery et al., 1989). 500 grams of cleaning solution was made; 400 grams for cleaning experiment and 100 grams for monitoring measurement such as electrical conductivity and titratable alkalinity. Table A.4. can show the reproducibility of each combination of the cleaning solutions.

3.5. Cleaning experiment

The cleaning experiments were executed in a glass jacketed container with internal diameter of 115 mm. Water from a controlled-temperature water bath was used to maintain constant temperatures in the jacket and within the cleaning agents at 25^{o}C during the experiments. After the initial mass of the foulant of each coupon was recorded, the fouled coupons were positioned at the edge of the base inside the glass container. As previously mentioned, 400 grams of cleaning solution sample was then poured inside the glass container. An overhead mixer (Caframo BDC250, Georgian Bluffs, Ontario N0H 2T0 Canada) was then set in the center of the glass container. The agitator was positioned to be 20 mm above the base of the glass container. The illustration of this set is shown in Figure 3.3.

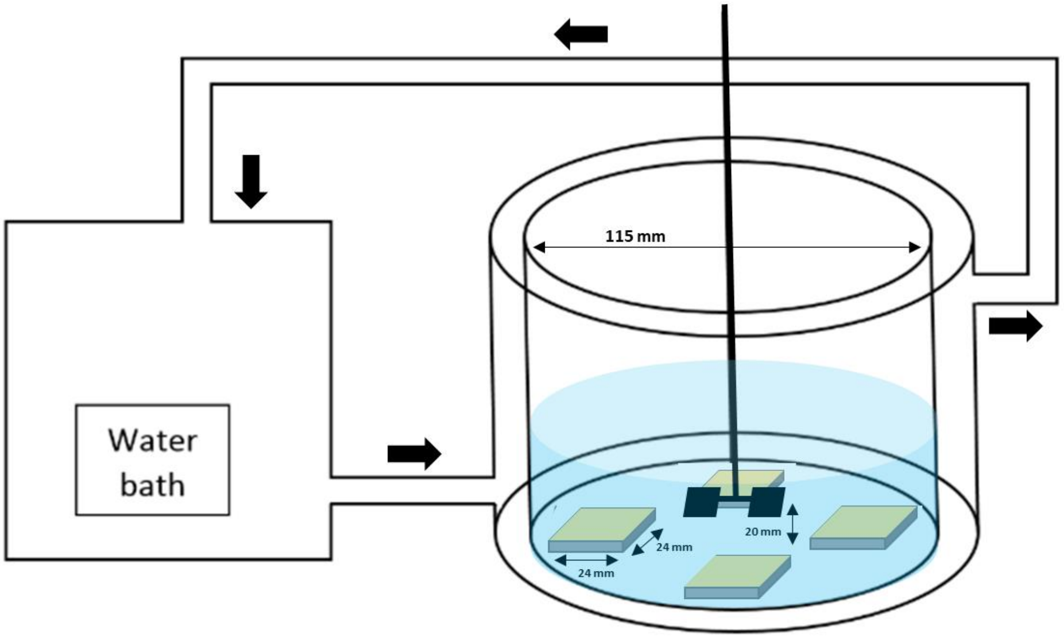

Figure 3.3. Schematic diagram of bench-top cleaning experiment set-up

The mixer was set to 300 rpm and the timer was started. The Reynolds number during this agitation could be calculated with formula below.

$$N_{Re} = \frac{{D_a}^2 N \rho}{\mu} \qquad (2)$$

where D_a is the agitator diameter in meter, N is the rotational speed in rotation per second, ρ is the density of the cleaning solution in kg/m3, and μ is the dynamic viscosity in kg/m.s. Since the composition of chemical cleaning is relatively small compared to water, the physical properties of the cleaning solution are assumed to be the same with water. At 25^{o}C, the viscosity and density of water are 8.937 x 10^{-4} kg/m.s and 997.08 kg/m^3 (Geankoplis, 1978), respectively. The diameter of agitator was measured to be around 34 mm. The Reynolds number calculation result is 6449, which is considered as transitional (Geankoplis, 1978).

Figure 3.4. Bench-top cleaning experiment set-up

The wall shear stress magnitudes were 0.55 Pa (Fan, 2018). The wall shear stress simulated in the bench-top set up was laminar and below the estimated wall shear stress of recommended velocity during cleaning in the industrial practice. The recommended velocity for cleaning was around 1.5 m/s and the wall shear stress was between 3 to 5.5 Pa (Blel et al., 2009; Dif et al., 2013; Fan, 2018; K. R. Goode et al., 2010). However, 300 rpm was chosen because higher speed will influence the result of the cleaning so much that the effect of cleaning solution is hardly observed.

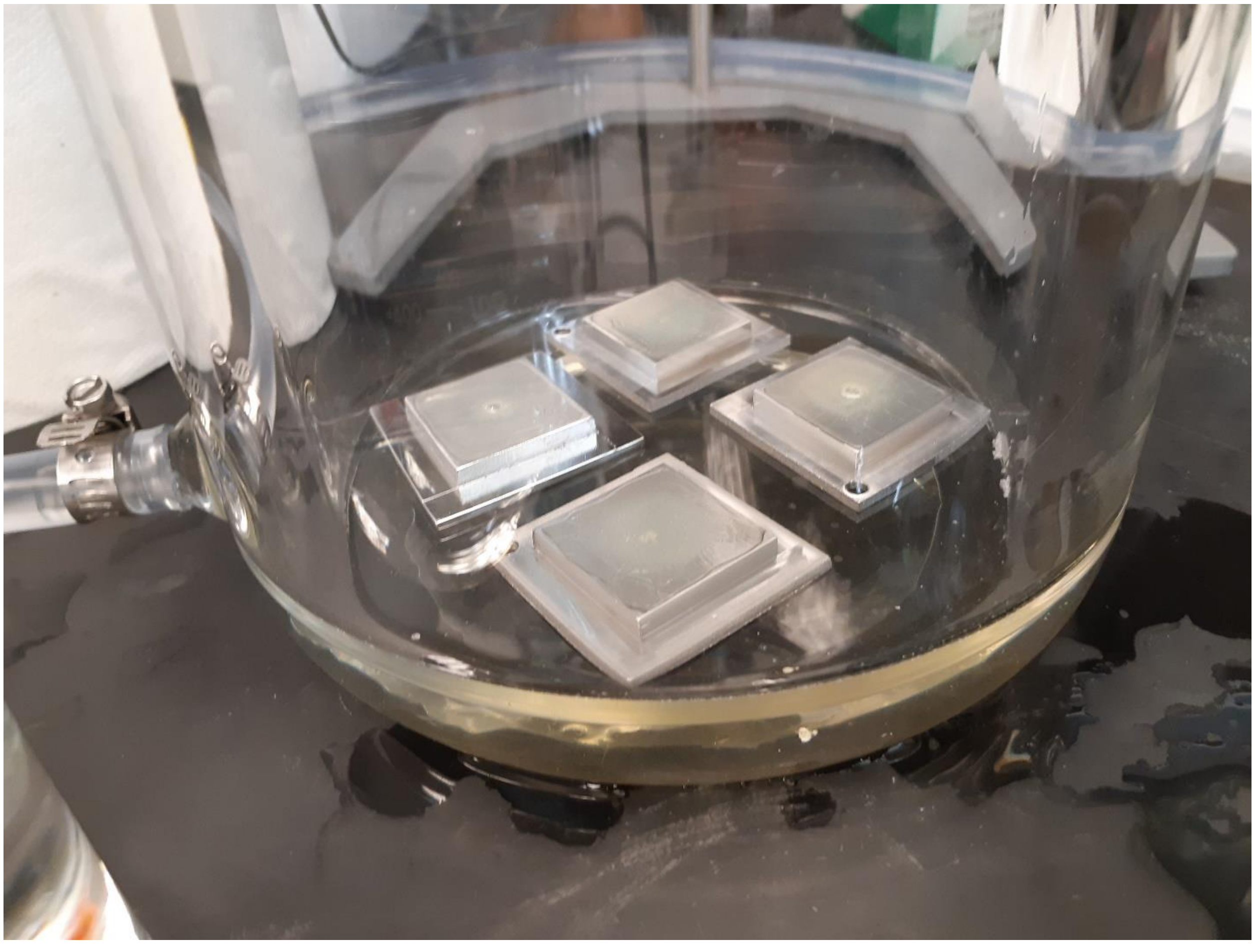

Figure 3.5. Coupon positioning inside the glass vessel.

The coupons were extracted randomly in 1, 5, 10, and 20 minutes intervals. The wet coupons were then stored in an oven at around 90-95^{o}C to dry for overnight. The mass after cleaning would then be measured on the day after.

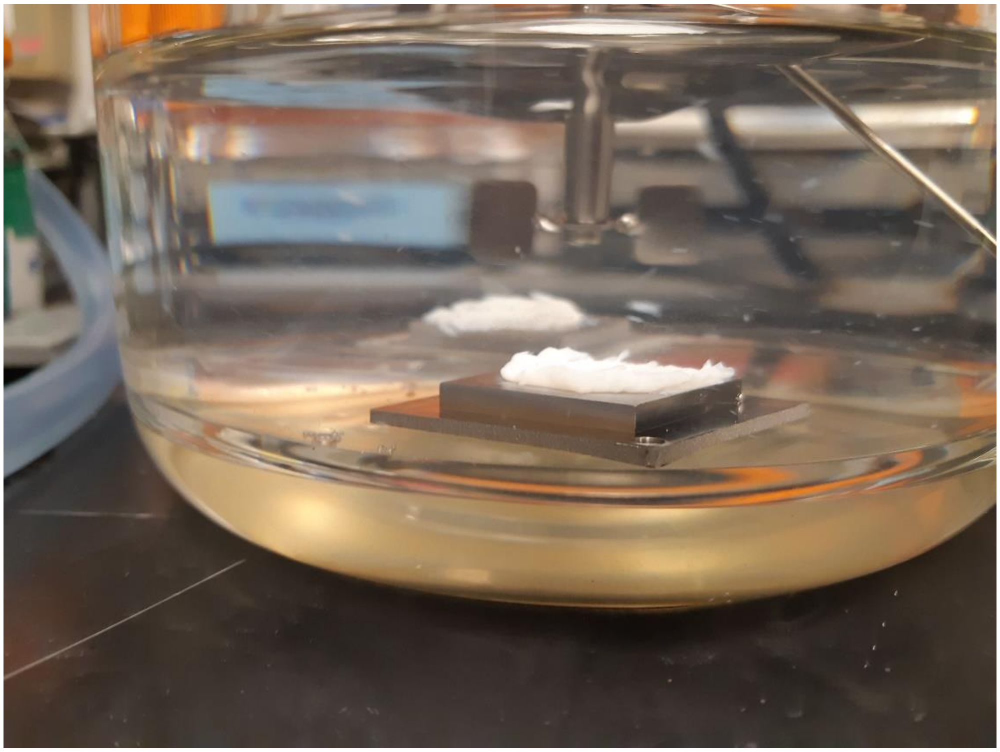

Figure 3.6. Picture of the coupon during cleaning experiment.

3.6. Experimental design

The study was divided to 3 different phases. The first phase was done to investigate the effect of sodium hydroxide concentration individually to the protein deposit removal rate. In this study, 8 different levels of sodium hydroxide were chosen: 0, 0.5, 5, 7.5, 15, 20, 30, and 60 kg/m^3. The second phase was done to understand the influence of sodium hypochlorite concentration individually to the protein removal rate. For this purpose, 6 different levels of sodium hypochlorite concentration were decided: 0, 50, 100, 150, 200, 300 ppm. The third phase was done to learn the effect of interaction between sodium hydroxide and sodium hypochlorite to the cleaning effectiveness. Based on the two previous studies, 4 level of each sodium hydroxide and sodium hypochlorite were chosen. Sodium hydroxide concentration of 0.5, 5, 7.5, and 15 kg/m^3 and sodium hypochlorite concentration of 50, 100, 150, and 200 ppm were decided to find if there was any interaction effect between the two compounds.

A 5x5 full factorial design was done to analyze the interaction between the sodium hydroxide and sodium hypochlorite concentration. The full factorial design incorporates the data from the two prior studies in which the effect of each compound was tested individually.

3.7. Data treatment

The data was analyzed using a first-order kinetic model as used in previous references (Fan, 2018; GrassBhoff, 1988; Hoffmann & Reuter, 1984; Jennings, 1965). The following first-order model has been used:

$$-\frac{dm}{dt} = km \tag{3}$$

$$\ln\frac{m}{m_0} = -kt \tag{4}$$

The rate constants (k) obtained from the first-order kinetic model of three replicates for each combination were the parameters of cleaning effectiveness: higher k means higher deposit removal. They were analyzed using ANOVA model to look for significant difference between each combination. The effect of each factors was determined according to confidence level of 95% (p-value < 0.05).

RESULTS AND DISCUSSION

4.1. Selecting the data to fit in the first-order kinetic model

In this study, 4 coupons were extracted in each experiment to represent 1 time point each. As mentioned previously, time points chosen for this study were 1, 5, 10, and 20 minutes. With the addition with the initial point, 5 time points could be plotted against the actual mass measured on the surface of the coupon.

From the raw data, effectiveness of cleaning would then be normalized to the initial mass of fouling and introduced as residual fouling (C/C_0) as displayed on Figure 4.1. From Figure 4.1., we can see that the 20 minutes data remained on the same range as the 10 minutes data. Student's t-test was then executed on the 10-minute and 20-minute data, and the conclusion was that they were not statistically different. This similar condition could also be observed in 18 other combinations as explained in Table 4.1. The pairs that were significantly different mostly were comprised of combination with low cleaning rate.

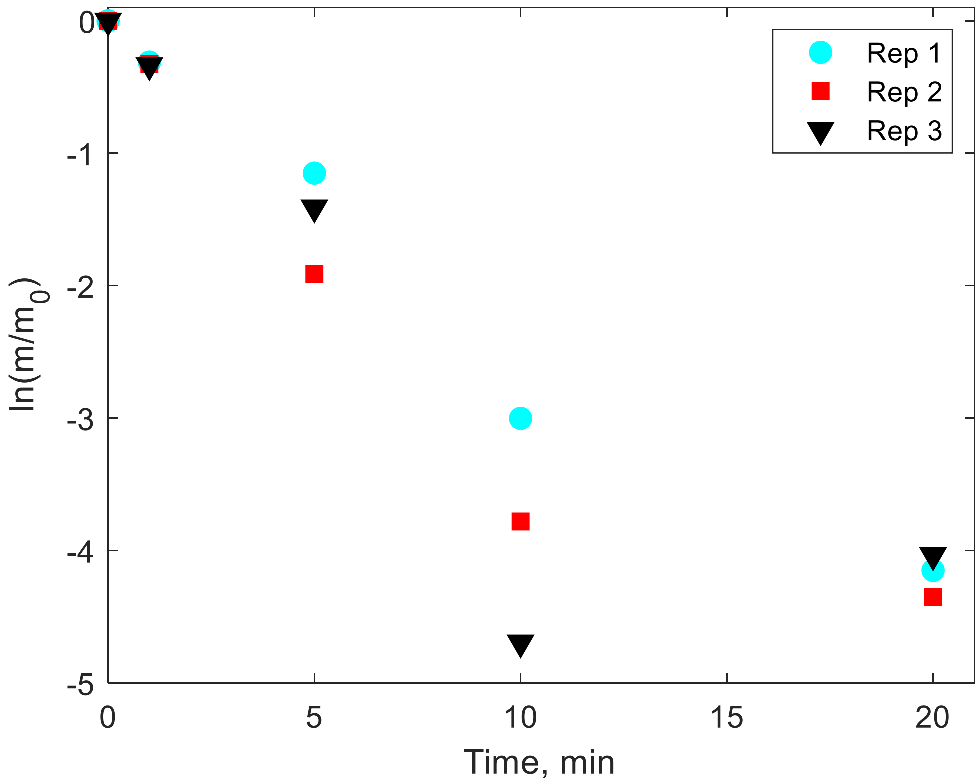

Figure 4.1. Example of the raw data of the cleaning effectiveness plot for 5 kg/m^3 NaOH vs 100 ppm NaClO with natural logarithms y-axis before analyzed with first-order kinetic model.

Table 4.1. Student's t-test on the residual fouling data at 10-minute and 20-minute mark on each combination (α = 0.05).

NaOH conc., kg/m^3	**NaClO conc., ppm**	**Mean at 10 mins**	**Mean at 20 mins**	**Difference**
0	0	0.4337	0.1434	Insignificant
0	50	0.2901	0.0863	Insignificant
0	100	0.3981	0.0371	Significant
0	150	0.4042	0.2701	Insignificant
0	200	0.3612	0.092	Insignificant
0.5	0	0.2035	0.0459	Significant

0.5	50	0.2556	0.014	Significant
0.5	100	0.1764	0.0231	Insignificant
0.5	150	0.2333	0.0202	Significant
0.5	200	0.2193	0.0526	Significant
5	0	0.0563	-0.00466	Significant
5	50	0.0122	0.0135	Insignificant
5	100	0.0272	0.0154	Insignificant
5	150	0.00729	0.0141	Insignificant
5	200	0.0193	0.0102	Insignificant
7.5	0	0.0421	0.0209	Insignificant
7.5	50	0.0232	0.0294	Insignificant
7.5	100	0.0178	0.0232	Insignificant
7.5	150	0.012	0.0139	Insignificant
7.5	200	0.026	0.02	Insignificant
15	0	0.0484	0.033	Insignificant
15	50	0.0889	0.0559	Insignificant
15	100	0.1912	0.042	Insignificant
15	150	0.1249	0.0471	Insignificant
15	200	0.0736	0.0557	Insignificant

This result indicated that there were two separate phases of cleaning observed with two different cleaning rates: before and after 10-minute mark. It was in accordance to the previous references (Gallot-Lavallee et al., 1984; Jennings, 1965; Melo et al., 1988). It was indicated by Gallot-Lavallee (1984) that the rate constant of first-order kinetic analysis increases significantly at first, then decreases over time.

For this study, we concentrated more on the first 10 minutes of the cleaning, which would remove the most amount of deposit. The difference between amount of fouling at 10-minute and 20-minute mark was not very significant, which indicated cleaning reaction rate considerably decreased after 10-minute. To be able to further analyze the second phase of the cleaning, more data should be collected after 10 minutes.

Up to 10 minutes, there are a total of 4 time points that can be analyzed with first-order kinetic model. The example of modeling curve-fits at 5 kg/m^3 of sodium hydroxide and 100 ppm of sodium hydroxide is represented at Figure 4.2., and the rest of each experiment are presented in Figure A.2. to Figure A.26.

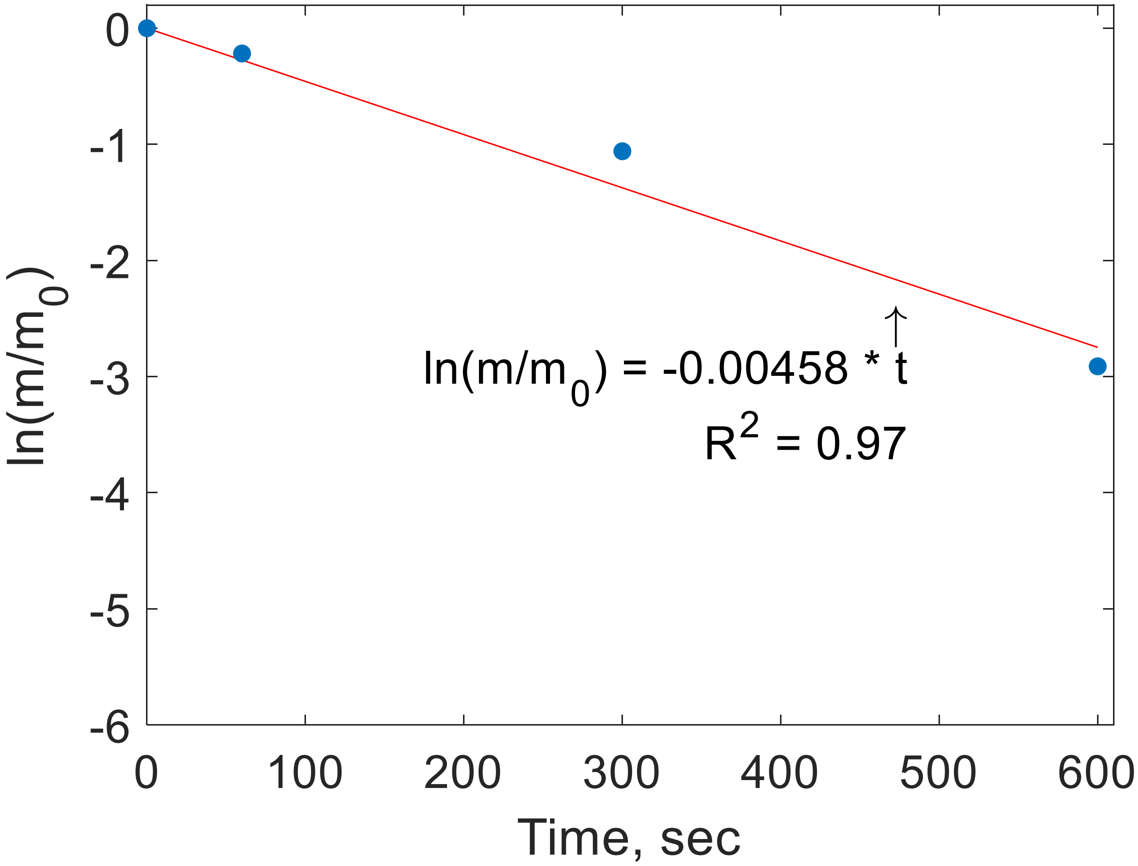

Figure 4.2. Curve-fit example of cleaning data at 5 kg/m^3 of sodium hydroxide concentration and 100 ppm of sodium hypochlorite concentration.

4.2. Effect of sodium hydroxide concentration without sodium hypochlorite in cleaning

The effect of sodium hydroxide concentration on the cleaning rate can be observed in Figure 4.3. This figure is presenting the effect of different sodium hydroxide concentration on the first-order cleaning rate constant. In this figure, it is apparent that the highest cleaning rate from the range studied is in the range between 5 and 15 kg/m^3.

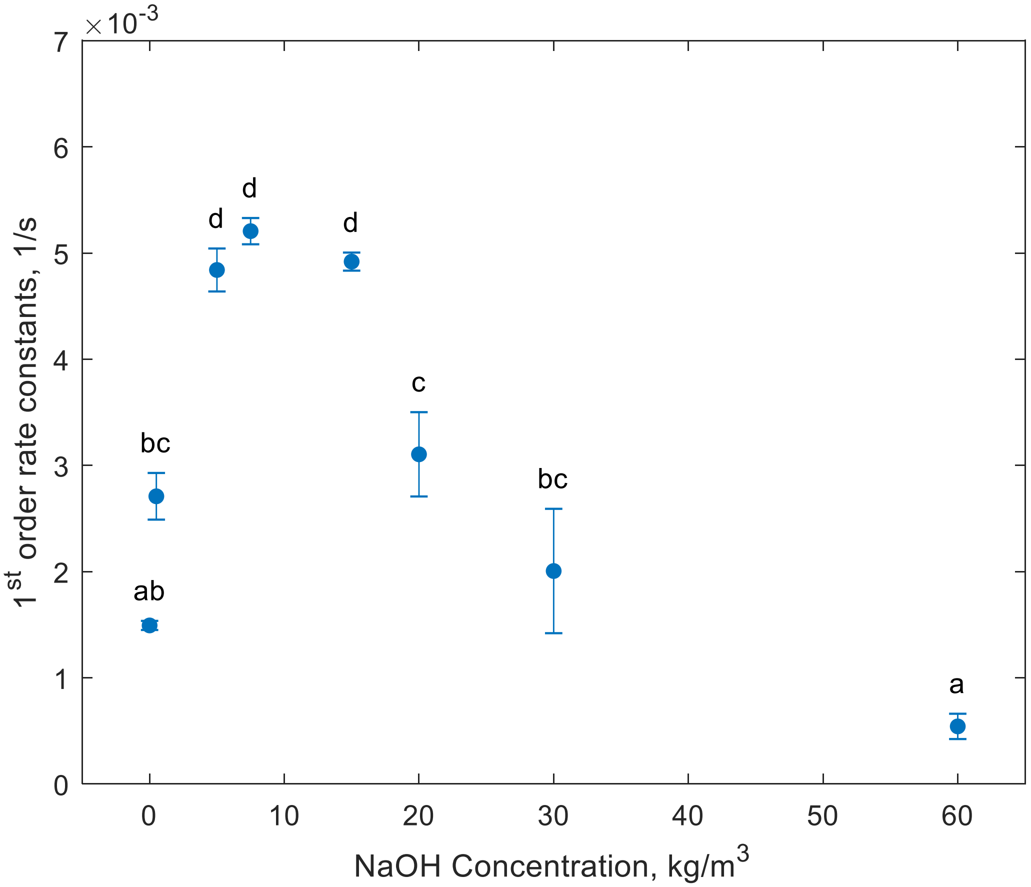

Figure 4.3. Effect of sodium hydroxide concentration on the first-order cleaning rate constant. Error bars represent standard error (n = 3).

From 0 to 5 kg/m^3 concentration of NaOH solution, higher concentration will increase the cleaning effectiveness. The concentration of 0 kg/m^3 means that the cleaning solution only contains water in it. Higher concentration improves the cleaning rate because it can create higher possibility of collision between sodium hydroxide compound to organic compound which creates protein matrix of high void fraction (swelling phase).

On the other hand, at the concentration above 15 kg/m^3, the cleaning rate constants decrease with higher concentration. The reason is that it increases the interaction between proteins by enhancing hydrogen bonding, hydrophobic interactions and disulfide bridges (Yang et al., 2019). This result is in accordance to previous references that higher concentration will not always result in higher cleaning effectiveness (Fryer et al., 2006; Timperley & Smeulders, 1988; Yang et al., 2019). Previous studies also demonstrated that higher concentration could make a closed structure in opposed to lower concentration and it inhibits the cleaning solution to penetrate further (Fryer et al., 2006).

4.3. Effect of sodium hypochlorite without sodium hydroxide in cleaning

The effect of sodium hypochlorite without sodium hydroxide compound on the first-order cleaning rates is represented in Figure 4.4. There is no significant difference between one point compared to each other in this data, which shows that cleaning by only sodium hypochlorite will only remove deposit as good as cleaning with water.

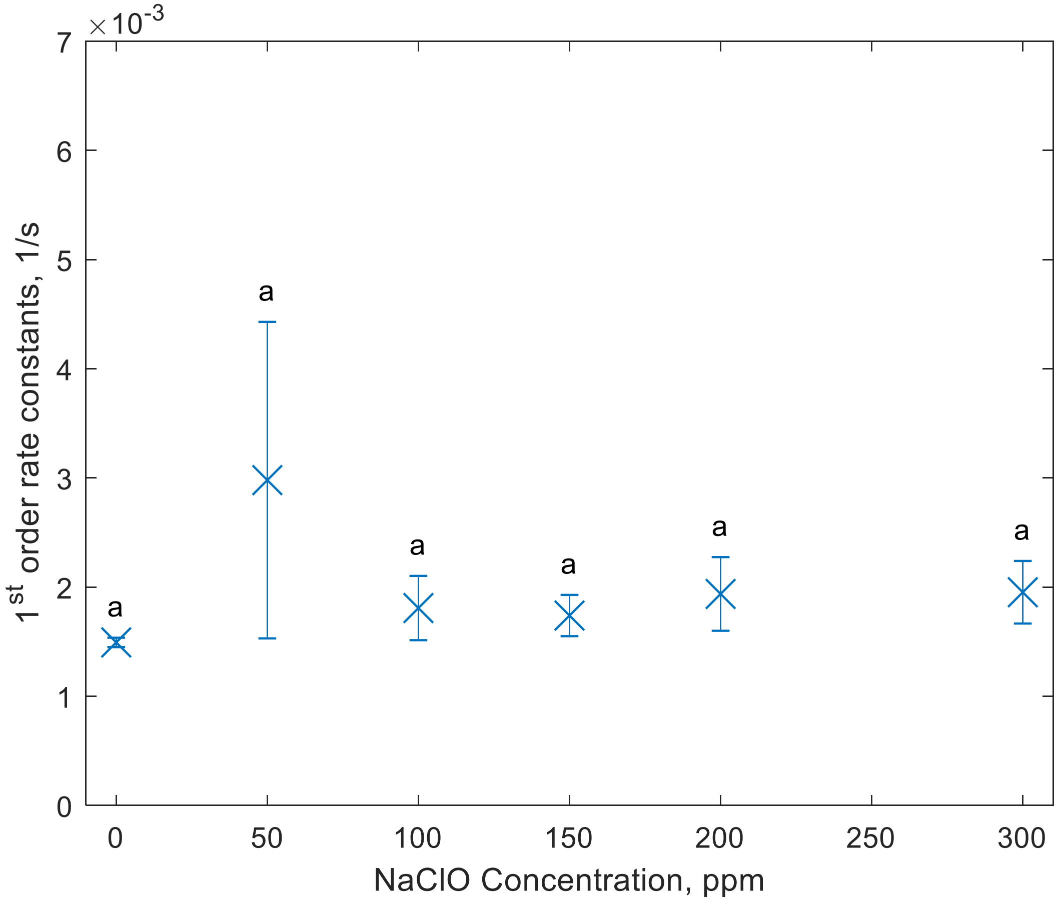

Figure 4.4. Effect of sodium hypochlorite concentration on the first-order cleaning rate constant. Error bars represent standard error (n = 3).

Despite widely known as sanitizing agents, sodium hypochlorite is helpful in cleaning when it is used at pH above 11 (Fukuzaki, 2006). It is because in that pH range, sodium hypochlorite is mostly in the form of OCl^- above the pH of 10. The pH of sodium hypochlorite by itself (without any sodium hydroxide) during the study was on the range of 9.48-10.47 as observed in Table A.4., which explains why the cleaning only by sodium hypochlorite was not very effective in this experiment.

4.4. Effect of the interaction between sodium hydroxide and sodium hypochlorite

Based on the result that was found in Figure 4.3. and Figure 4.4., range of sodium hydroxide and sodium hypochlorite are decided. For sodium hydroxide, a range of 0 to 15 kg/m^3 is chosen as the main objective of this study is to minimize the usage of chemical in cleaning to have a more sustainable operation. Despite the maximum concentration found at 7.5 kg/m^3, the concentration of 15 kg/m^3 did not make a significant difference. For sodium hypochlorite, as no significant difference is found between 0 to 300 ppm, the range of sodium hypochlorite for further study is limited to 200 ppm in accordance to maximum usage recommendation for food-contact surface by EPA.

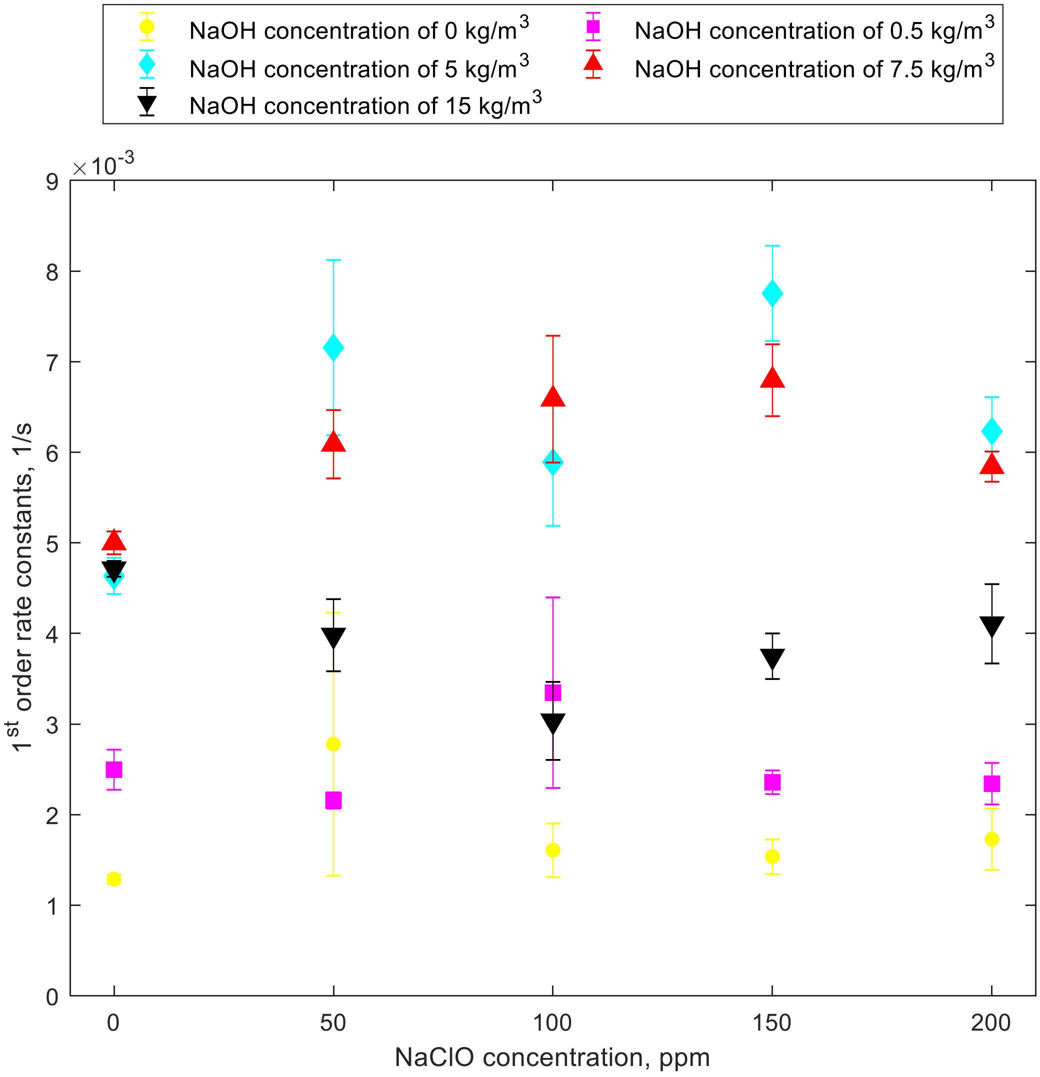

Figure 4.5. The effect of sodium hypochlorite concentration on the first-order rate constants at different level of sodium hydroxide concentration. Error bars represent standard error (n = 3).

Figure 4.5. is showing the effect of sodium hypochlorite on the first-order kinetic model rate constants at different level of sodium hydroxide concentration. It can be observed that there is no

significant difference between the cleaning rates at sodium hydroxide concentration level of 0 kg/m^3 as similarly concluded from Figure 4.5. Similar conclusion is achieved at sodium hydroxide concentration of 0.5 kg/m^3 and sodium hydroxide concentration of 7.5 kg/m^3. At the sodium hydroxide concentration of 5 kg/m^3, the increase of sodium hypochlorite concentration in cleaning solution does not make consistent trend. At the sodium hydroxide concentration of 15 kg/m^3, a concave-up trend is apparent, where the sodium hypochlorite concentration at 100 ppm is shown to be the slowest compared to the other sodium hypochlorite concentration at the same level of sodium hydroxide concentration.

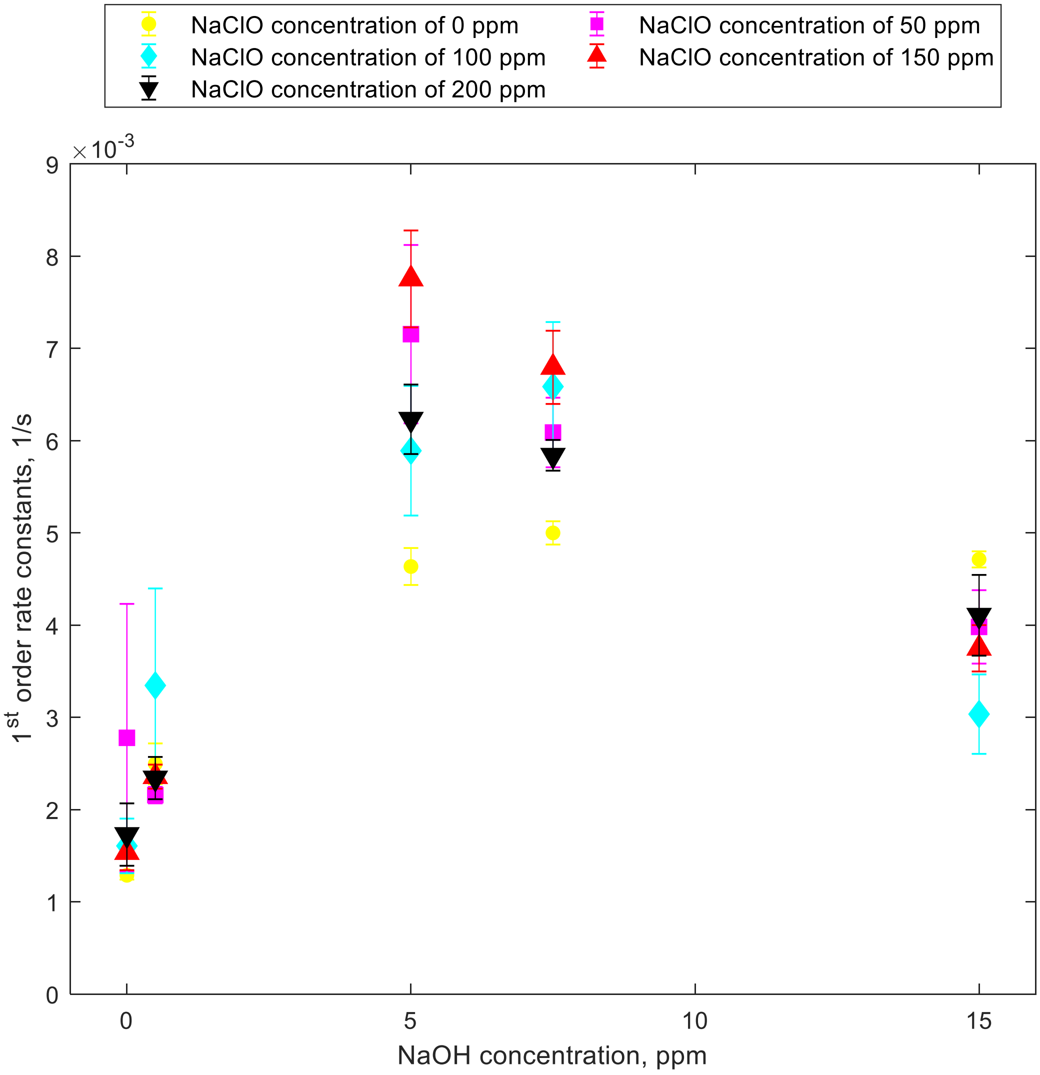

Figure 4.6. The effect of sodium hydroxide concentration on the first-order rate constants at different level of sodium hypochlorite concentration. Error bars represent standard error (n = 3).

Figure 4.6. is showing the effect of sodium hydroxide concentration on the first-order kinetic model rate constants at different level of sodium hypochlorite concentration levels. The effect of

sodium hydroxide concentration without sodium hypochlorite addition is shown in yellow circle marks, which is the same with Figure 4.3. Along the sodium hydroxide concentration, we can see that there is an optimum range around 5 and 7.5 kg/m^3 where the cleaning rate constants show relatively higher results. Looking at the data within each concentration of sodium hydroxide, we can see that the data is quite clustered together, which emphasize the relatively insignificant effect of sodium hypochlorite addition.

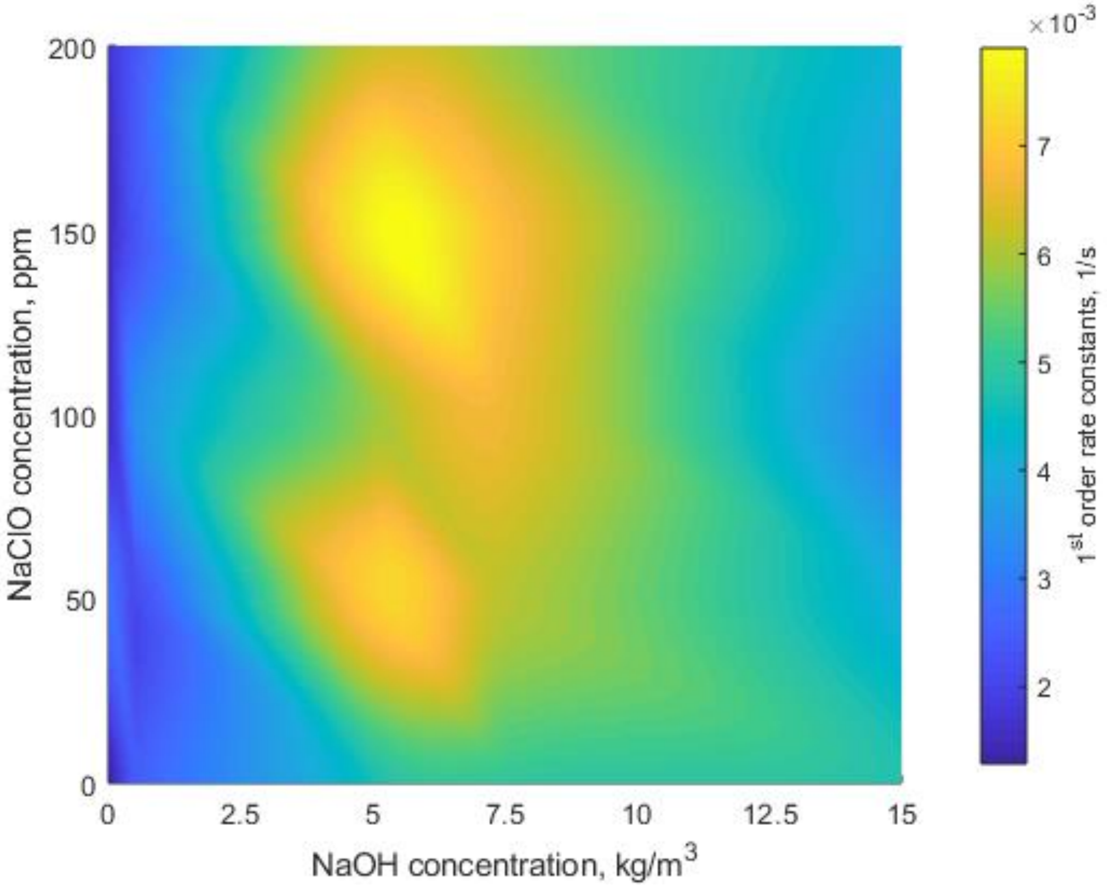

Figure 4.7. Contour plot of the effect of sodium hydroxide (NaOH) and sodium hypochlorite (NaClO) concentration on the first-order rate constant.

To summarize the results, Figure 4.7. is used to show the effect of the combination between sodium hydroxide and sodium hypochlorite concentration on the first-order kinetic model cleaning rate constant. The constants are represented with the scale bar: the lowest rate constant was in dark blue color, while the highest rate constant in yellow. The figure shows that the difference in sodium hypochlorite concentration did not create much difference except at sodium hydroxide concentration around 5-7.5 kg/m^3.

It is previously believed that adding sodium hypochlorite in sodium hydroxide cleaning solution will improve the cleaning effectiveness, which in this study is represented in the first-order rate constant. However, statistical analysis on Table 4.3. shows that the interaction between these two compounds are not significant at $\alpha = 0.05$. Table 4.5. shows that the cleaning rate is only affected by the sodium hydroxide concentration.

On Figure 4.6. and Figure 4.7., we can see that sodium hydroxide concentration creates significant differences on the first-order rate constants. Both the interaction of between sodium hydroxide and sodium hypochlorite and the main effect of sodium hypochlorite were shown to be insignificant factor at $\alpha = 0.05$. This finding is in contrast with previous references where sodium hypochlorite was considered as an effective additive to the sodium hydroxide cleaning solution (R. W. R. Baker, 1947; Fukuzaki, 2006; MacGregor et al., 1954).

Baker (1947) and Macgregor (1954) measured the concentration of left-over sodium hypochlorite in the cleaning solution to represent the effectiveness of cleaning. The decrease in the sodium hypochlorite concentration might be caused by many different possibilities other than the removal of protein deposits. High temperature can cause faster decomposition to the sodium hypochlorite compared to lower temperature. Exposure to UV can also catalyze the decomposition reaction (Adam & Gordon, 1999). In Baker's study, the temperature of the cleaning was 71^{o}C and there is no information about limiting the exposure to UV light.

4.5. ANOVA model of cleaning

Since there are 2 independent variables analyzed (the effects of sodium hydroxide and sodium hypochlorite concentration), the full ANOVA model equation will be as follows.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{1*1} X_{1*1} + \beta_{2*2} X_{2*2} + \beta_{1*2} X_{1*2} + \in \qquad (4)$$

Y = dependent variable (cleaning reaction first-order rate constant)

β_0 = estimate of intercept (without NaOH and NaClO)

β_1, β_2 = estimate of main effect of first (NaOH concentration) and second (NaClO concentration) independent variable

β_{1*1}, β_{2*2} = estimate of quadratic term of first (NaOH concentration) and second (NaClO concentration) independent variable

β_{1*2} = estimate of cross-interaction term of first (NaOH concentration) and second (NaClO concentration) independent variable

X_1, X_2 = main effect of first (NaOH concentration) and second (NaClO concentration) independent variable

X_{1*1}, X_{2*2} = quadratic term of first (NaOH concentration) and second (NaClO concentration) independent variable

X_{1*2} = cross-interaction term between first (NaOH concentration) and second (NaClO concentration) independent variable

The significance of the ANOVA model is shown from Table 4.2. Based on the ANOVA equations above, we can see the significance of each main effect, the quadratic terms, and the cross-interaction of both independent variables. The estimates of these parameters are represented in Table 4.3.

Table 4.2. ANOVA table of the full model

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	5	0.00024624	0.000049	42.8142
Error	69	0.00007937	1.15E-06	**Prob > F**
C. Total	74	0.0003256		<.0001*

Table 4.3. Parameter estimates of each effect of the full model

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-0.00405	0.000294	-13.76	<.0001*
NaOH	-0.00037	2.86E-05	-13.01	<.0001*
NaClO	-1.71E-06	1.75E-06	-0.97	0.3331
(NaOH-5.6)*(NaClO-100)	1.17E-07	3.20E-07	0.36	0.7164
(NaOH-5.6)*(NaOH-5.6)	6.45E-05	4.95E-06	13.03	<.0001*
(NaClO-100)*(NaClO-100)	4.86E-08	2.96E-08	1.64	0.1049

From Table 4.2., we can deduce that the full model generated is significant (p-value < 0.0001). And from Table 4.3., the only significant parameters are the main effect of intercept and sodium hydroxide concentration, and quadratic term effect of sodium hydroxide concentration. Considering the p-value of each parameter, we should remove the insignificant parameters ($p > 0.05$) and see how the significance of other parameters change.

The first insignificant parameter that is recommended to be removed are the ones from higher order. There are two insignificant parameters from the higher order: one from the cross-interaction of sodium hydroxide and sodium hypochlorite concentration and the other one from quadratic term of sodium hypochlorite concentration. However, since we are still interested in observing the effect of cross-interaction effect, the quadratic term is removed first. The result of the ANOVA table and its estimates are presented in Appendix at Table A.5. and Table A.6. respectively.

As we can observe in Table A.5., the analysis of variance model is still significant with p-value < 0.0001. With one insignificant factor removed, the p-values of the other factors slightly changes. Similar to the previous full model, the main effect of sodium hypochlorite concentration and the cross-interaction effect between sodium hydroxide and sodium hypochlorite are still insignificant at $\alpha = 0.05$. The next higher-order term that can be eliminated from the ANOVA model is the cross-interaction effect as shown in Appendix at Table A.7. and Table A.8.

Table A.7. shows that the ANOVA model is significant with p-value < 0.0001. The factors observed in Table A.8. shows that the concentration of sodium hypochlorite is still not significant at $\alpha = 0.05$. The main effect of sodium hypochlorite concentration has to be removed from the statistical model as well so that only the significant parameters are present.

Table 4.4. ANOVA table of the statistical model after removing all the insignificant effects.

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	2	0.00024189	0.000121	104.0136
Error	72	0.00008372	1.16E-06	**Prob > F**
C. Total	74	0.0003256		<.0001*

Table 4.5. Parameter estimates of each effect of ANOVA of all the significant effects.

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-0.003975	0.000185	-21.47	<.0001*
NaOH	-0.000372	2.88E-05	-12.94	<.0001*
(NaOH-5.6)*(NaOH-5.6)	0.0000645	4.98E-06	12.96	<.0001*

As shown in Table 4.4., the ANOVA model is significant with p-value < 0.0001. Table 4.5. only consists of significant parameters at $\alpha = 0.05$ as the insignificant ones were removed previously. It is shown that the cleaning rate was influenced only by the concentration of the sodium hydroxide. The effect of sodium hydroxide was both in linear and quadratic term. The result of this ANOVA analysis supports the findings we found earlier in Figure 4.3., Figure 4.4., and Figure 4.7.

Table 4.6. Power analysis and least significant number of samples of insignificant parameters.

Parameters	**Power**	**Least Significant Number**
NaClO	0.292	139
NaClO * NaClO	0.358	112
NaOH * NaClO	0.1315	400

The power analysis shows that the statistical power of the effect of sodium hydroxide concentration in linear term and quadratic term are both 1.00, which is the highest value possible. This means there is no probability of type-2 error happening as the probability is calculated by subtracting one from the power value. Type-2 error means not rejecting the null hypothesis when it is actually false. In the case of this study, the null hypothesis is that each main effect and interaction effect analyzed does not create any significant difference. Based on this information, least significant number of samples can be calculated and become the basis of subsequent study. However, it does not necessarily mean the significance of the factor will be found after having the mentioned number of samples.

The power of the three insignificant terms that were removed in the statistical model (linear term of sodium hypochlorite, quadratic term of sodium hypochlorite, and the cross-interaction of sodium hypochlorite and sodium hydroxide) were also analyzed and presented in Table 4.6.

4.6. Optimum concentration of the combination between sodium hydroxide and sodium hypochlorite

As described in Table 4.5., the first-order rate constants for cleaning reaction are influenced by the concentration of sodium hydroxide in linear and quadratic term. The concentration of sodium hypochlorite and its interaction with sodium hydroxide are found to be insignificant at α = 0.05.

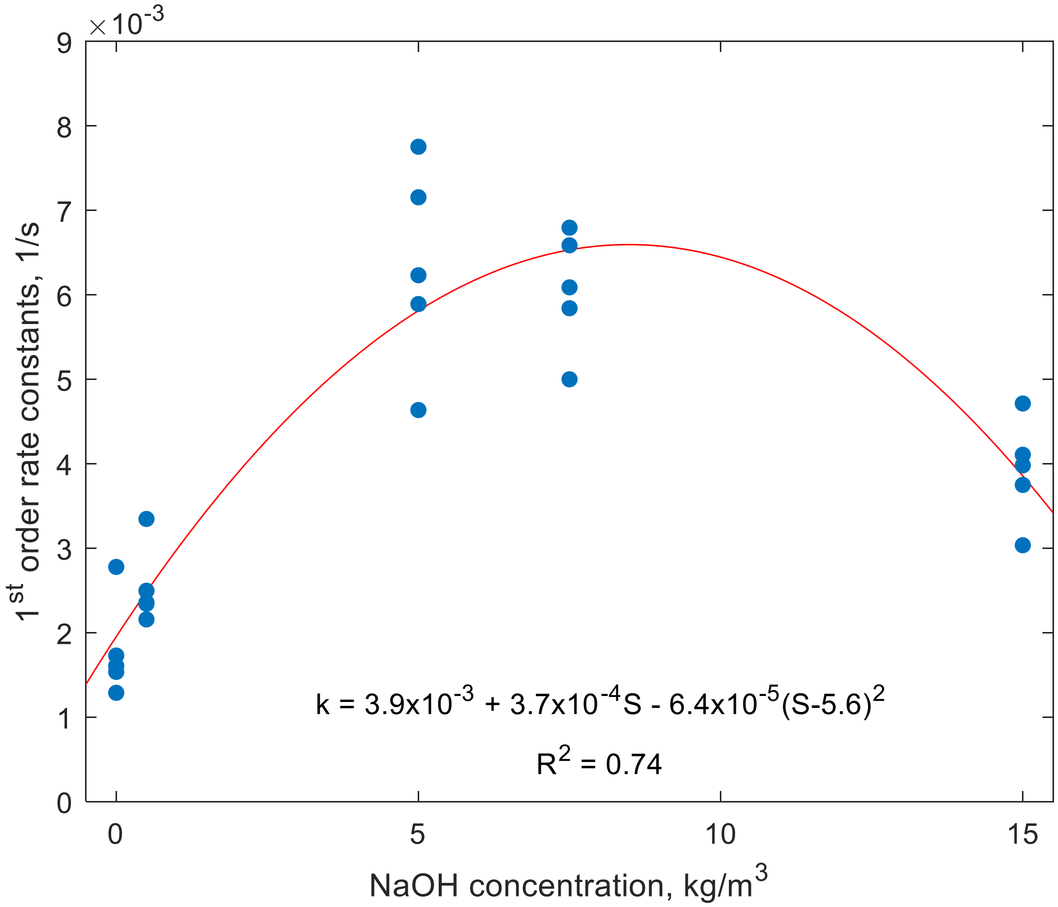

Figure 4.9. Actual first-order rate constant data compared to the prediction based on the statistical model derived from one-way ANOVA.

Indicated in Figure 4.9., the blue dots are the average of cleaning rates at different combination between sodium hydroxide and sodium hypochlorite. As previously concluded in Section 4.5., both the effect of sodium hypochlorite and its interaction with sodium hydroxide are not significant factors in cleaning. The red line is showing the prediction of cleaning rate based on the estimate of the intercept, linear main effect of sodium hydroxide, and quadratic term of sodium hydroxide. The coefficient for the prediction equation was from the ANOVA analysis at Table 4.5. The following equation was used for prediction:

$$k = 3.9 \times 10^{-3} + 3.7 \times 10^{-4} S - 6.4 \times 10^{-5} (S - 5.6)^2 \qquad (5)$$

where k is the first-order rate constant and S is the concentration of sodium hydroxide.

The predicted optimum concentration is the lowest concentration of chemicals to provide highest cleaning rate. From Figure 4.9., the maximum rate constant predicted is 6.6 x 10^{-3} s^{-1}. The concentration of sodium hydroxide to get this cleaning rate constant is 8.48 kg/m^3.

CONCLUSIONS

The results of this study confirm that the influence of sodium hydroxide concentration is significant to the protein deposit removal ($p < 0.05$). Between the range of 0 to 60 kg/m^3, highest cleaning rate constant was found between sodium hydroxide concentration of 5 to 15 kg/m^3. Below the range, increasing sodium hydroxide concentrations will result in increasing cleaning rate constants. Above the range, the rate constants decrease as the concentrations get higher.

In the range of concentration investigated in this study (between 0 ppm to 300 ppm), sodium hypochlorite is not found to be a significant factor in protein deposit removal when it is used by itself ($p > 0.05$). The interaction between sodium hydroxide and sodium hypochlorite is also not considered to be significantly influencing the cleaning rate constants ($p > 0.05$).

Sodium hydroxide concentration is the only significant factor in affecting the cleaning constant rate. The effect was found to relate the cleaning rate in quadratic polynomial form. The highest cleaning rate constant is predicted at the sodium hydroxide concentration of 8.48 kg/m^3.

FUTURE RESEARCH

This research investigated the influence of sodium hypochlorite and sodium hydroxide concentration on protein deposit removal in room temperature cleaning. Further study needs to be done to understand the effect of temperature to cleaning solutions comprised of these compounds. Higher temperature is believed to increase the chemical cleaning reaction. However, it might make sodium hypochlorite compound less stable.

In the industry, sodium hypochlorite also acts as a sanitizer in addition to improve the cleaning effectiveness alkali cleaning step. The operators would then remove the sanitizing step since it has been done together in this cleaning step. The impact of sodium hypochlorite in sanitizing together with cleaning also needs to be investigated further. The impact of sodium hypochlorite in removing biofilm also needs to be studied.

This study investigated the effect of protein deposit removal with a model foulant from reconstituted skim milk. The milk was then heated in 75^{o}C oven for an hour. Although this foulant has been used in many previous references and can represent a protein fouling layer, a more industrial-like fouling also needs to be developed. Therefore, the usage of pilot scale set up is also important to mimic the condition in food manufacturing plant.

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APPENDIX

Table A.1. Raw data of the influence of sodium hydroxide on cleaning effectiveness.

No.	NaOH Conc., kg/m^3	Time, min	Plate, gram	Coupon, gram	Milk1, gram	Dry1, gram	Clean, gram	DryClean, gram
1	30	1	2.4056	34.6455	35.2451	34.7689	35.0147	34.7603
2	30	20	2.4392	28.7954	29.4159	28.9228	29.3122	28.846
3	30	5	2.4415	31.1347	31.7137	31.2525	31.5692	31.2171
4	30	10	2.4279	34.9286	35.5475	35.0575	35.419	34.9945
5	5	5	2.4467	34.8902	35.5118	35.017	35.117	34.9266
6	5	10	2.4344	29.709	30.3255	29.8333	29.849	29.714
7	5	1	2.4737	28.8285	29.4669	28.9589	29.1014	28.9226
8	5	20	2.4674	29.5864	30.2189	29.7167	29.7186	29.5861
9	7.5	10	2.4241	34.916	35.562	35.0493	35.0666	34.9213
10	7.5	5	2.4619	35.1924	35.8211	35.3219	35.392	35.2267
11	7.5	1	2.4138	31.6975	32.3274	31.8273	32.0048	31.7939
12	7.5	20	2.4472	34.9386	35.5054	35.0539	35.1357	34.9412
13	15	10	2.4303	34.9549	35.5956	35.0889	35.0962	34.9608
14	15	1	2.4644	31.0188	31.6505	31.1497	31.3382	31.1202
15	15	5	2.4693	31.0038	31.6163	31.1298	31.2189	31.0396
16	15	20	2.458	31.6814	3.2764	31.8029	31.8171	31.6861
17	5	5	2.4718	30.022	30.6803	30.1557	30.1807	30.0547
18	5	10	2.3979	35.0538	35.6906	35.184	35.1852	35.0603
19	5	20	2.4699	35.1622	35.7955	35.2923	35.3218	35.161
20	5	1	2.4528	31.3638	31.992	31.493	31.6647	31.4466
21	0.5	5	2.468	34.6733	35.28	34.8011	35.007	34.7335
22	0.5	10	2.4191	34.9402	35.5138	35.0582	35.295	34.971
23	0.5	20	2.4305	34.7441	35.3897	34.8791	34.9628	34.7474
24	0.5	1	2.4053	34.7409	35.3621	34.8726	35.164	34.8315
25	0	10	2.4933	29.8092	30.4407	29.9427	30.313	29.8629
26	0	5	2.4413	34.6736	35.3096	34.8062	35.1023	34.7542
27	0	20	2.4113	34.096	34.7366	34.2281	34.2872	34.0937
28	0	1	2.4749	34.3143	34.9456	34.4478	34.6729	34.4096
29	0.5	20	2.4427	35.0006	35.6077	35.1268	35.3768	35.0065
30	0.5	5	2.4794	29.765	30.3768	29.8913	30.0838	29.8247
31	0.5	1	2.4454	29.8145	30.4424	29.9421	30.2014	29.9047
32	0.5	10	2.4418	34.9496	35.568	35.0766	35.1949	34.9741

33	60	1	2.4294	34.8402	35.4539	34.9628	35.1905	34.9737
34	60	5	2.4154	31.2287	31.8504	31.3533	31.626	31.3271
35	60	20	2.4145	34.9971	35.6107	35.127	35.2285	35.0386
36	60	10	2.4324	35.1477	35.7809	35.2768	35.5088	35.2281
37	30	5	2.4155	34.8462	35.4441	34.9656	35.1088	34.8877
38	30	10	2.4412	34.7319	35.3478	34.8552	34.9239	34.7519
39	30	20	2.4332	34.5856	35.2229	34.7138	34.7759	34.5988
40	30	1	2.4294	34.857	35.4575	34.9805	35.1763	34.9685
41	15	5	2.4696	34.4306	35.0318	34.5519	34.6245	34.4682
42	15	20	2.4775	35.0521	35.6865	35.1811	35.2222	35.0577
43	15	10	2.4531	31.2569	31.8817	31.3845	31.4455	31.2634
44	15	1	2.467	29.7034	30.3133	29.8302	29.9923	29.7999
45	5	20	2.4627	29.8319	30.4428	29.9546	30.0686	29.8316
46	5	1	2.4684	29.7835	30.4044	29.91	30.0732	29.8789
47	5	10	2.4172	34.9243	35.5631	35.0549	35.0855	34.9346
48	5	5	2.4685	35.125	35.757	35.2561	35.3682	35.1518
49	15	1	2.4701	34.3079	34.9289	34.4338	34.5993	34.4039
50	15	10	2.4155	35.1088	35.7379	35.236	35.2182	35.1152
51	15	20	2.4179	31.3296	31.9618	31.4593	31.4773	31.3318
52	15	5	2.4785	34.7913	35.4195	34.9206	34.9887	34.8189
53	30	1	2.478	29.764	30.3874	29.8899	30.1045	29.8697
54	30	20	2.419	30.9734	31.6315	31.1064	31.1368	30.9908
55	30	10	2.4292	28.7829	29.4245	28.9127	29.1112	28.8258
56	30	5	2.4187	34.8619	35.4749	34.9887	35.3681	34.9453
57	20	20	2.48	34.7613	35.4023	34.8886	35.1046	34.7758
58	20	5	2.4611	34.6668	35.2863	34.7912	34.9205	34.7121
59	20	10	2.4845	29.6046	30.2595	29.7386	29.8592	29.6165
60	20	1	2.4636	29.7381	30.3854	29.87	30.0551	29.8454
61	20	20	2.4309	35.2534	35.9065	35.3845	35.4773	35.2655
62	20	1	2.4439	35.1745	35.824	35.3059	35.6179	35.2856
63	20	5	2.4561	29.7719	30.3997	29.8998	30.0905	29.8194
64	20	10	2.4497	31.7341	32.3749	31.8666	32.1007	31.7627
65	60	1	2.4315	34.6636	35.274	34.7876	35.1156	34.8239
66	60	10	2.4416	29.8101	30.4476	29.9397	30.2585	29.8952
67	60	5	2.4657	31.1497	31.7934	31.2829	31.6776	31.2907
68	60	20	2.4386	31.0529	31.6805	31.1831	31.5165	31.1174
69	20	10	2.4657	30.0151	30.6225	30.1383	30.3041	30.0379
70	20	5	2.4532	34.9451	35.5856	35.0766	35.3449	35.0115
71	20	20	2.4611	34.9605	35.6118	35.0937	35.1151	34.9652
72	20	1	2.4452	31.668	32.2926	31.7969	32.0153	31.7739
73	7.5	20	2.4545	34.1395	34.7611	34.2632	34.3169	34.1415

74	7.5	10	2.469	31.0041	31.6261	31.1288	31.175	31.0111
75	7.5	5	2.4639	34.7973	35.4178	34.9178	35.0643	34.8184
76	7.5	1	2.4156	34.908	35.5375	35.0368	35.2402	35.0018
77	0.5	10	2.4171	35.1346	35.7397	35.2598	35.4394	35.1542
78	0.5	20	2.4051	35.0606	35.6759	35.1853	35.4462	35.0689
79	0.5	5	2.592	34.7523	35.3591	34.8755	35.162	34.8031
80	0.5	1	2.4258	34.5817	35.1795	34.7053	34.8858	34.6689
81	60	1	2.422	31.3331	31.9472	31.46	31.7248	31.4929
82	60	20	2.4302	34.391	34.9803	34.5128	34.7915	34.4581
83	60	5	2.392	34.8224	35.4198	34.9463	35.2328	34.9304
84	60	10	2.4062	29.6425	30.2534	29.7711	30.1488	29.7442
85	0	10	2.424	31.2377	31.8547	31.3646	31.7754	31.2945
86	0	1	2.3873	34.8967	35.4966	35.0177	35.344	34.9908
87	0	5	2.4634	35.1563	35.7564	35.2809	35.577	35.2285
88	0	20	2.4413	34.7547	35.3507	34.8769	35.0966	34.7662
89	0	5	2.4431	34.8574	35.482	34.9853	35.3976	34.9328
90	0	20	2.4271	34.8591	35.4604	34.981	35.4225	34.9022
91	0	10	2.4095	29.7782	30.3875	29.9036	30.2563	29.8348
92	0	1	2.4166	29.7323	30.3575	29.8629	30.0795	29.8278
93	7.5	5	2.4291	31.2329	31.8663	31.3608	31.4434	31.2731
94	7.5	20	2.4164	34.9926	35.5847	35.1134	35.2263	34.9955
95	7.5	1	2.4385	34.7367	35.3629	34.852	35.0313	34.8202
96	7.5	10	2.4403	35.0267	35.6606	35.1584	35.2415	35.0307

Table A.2. Raw data of the influence of sodium hypochlorite on cleaning effectiveness.

No.	NaClO Conc., ppm	Time, min	Plate, gram	Coupon, gram	Milk1, gram	Dry1, gram	Clean, gram	DryClean, gram
1	200	5	2.4084	29.7793	30.4033	29.9062	30.2408	29.8369
2	200	10	2.4306	29.7061	30.3391	29.831	30.3815	29.77
3	200	1	2.4491	35.1803	35.8194	35.3079	35.4812	35.2844
4	200	20	2.376	31.6607	32.2742	31.7868	32.0379	31.6794
5	300	1	2.4344	29.7516	30.3791	29.8794	30.0868	29.8516
6	300	10	2.4217	34.9156	35.5711	35.0501	35.6396	34.9798
7	300	20	2.4261	29.7126	30.3784	29.8498	30.3037	29.7577
8	300	5	2.4431	35.2618	35.9304	35.4011	35.5436	35.3061
9	100	1	2.4648	34.6703	35.3109	34.8017	35.0531	34.7693

10	100	10	2.4094	34.9331	35.5774	35.0633	35.6879	34.9886
11	100	5	2.4109	34.7463	35.3636	34.8729	35.2981	34.8164
12	100	20	2.4547	30.9899	31.6278	31.1232	31.3579	31.0088
13	150	10	2.4155	30.971	31.582	31.0992	31.6462	31.0223
14	150	5	2.4002	31.6269	32.2573	31.7569	32.2864	31.7036
15	150	20	2.4535	34.9746	35.5903	35.1014	35.6639	35.0157
16	150	1	2.4266	34.9195	35.5628	35.0538	35.3513	35.0196
17	50	20	2.4658	29.5855	30.2409	29.722	29.981	29.6147
18	50	10	2.4109	34.9687	35.6088	35.0996	35.6359	35.0305
19	50	5	2.4505	34.2892	34.9449	34.4247	34.7832	34.369
20	50	1	2.4121	34.0969	34.7496	34.2329	34.3986	34.1976
21	50	5	2.4426	34.8564	35.4724	34.9836	35.2914	34.9176
22	50	10	2.4137	31.106	31.7213	31.2321	31.6613	31.1585
23	50	1	2.4425	34.4127	35.0026	34.5334	34.7305	34.5021
24	50	20	2.413	34.9891	35.5753	35.1108	35.2389	34.9884
25	150	5	2.3977	34.8335	35.4452	34.9613	35.4695	34.8966
26	150	10	2.404	35.0964	35.7084	35.2221	35.7791	35.1556
27	150	20	2.4053	35.0607	35.6761	35.188	35.7702	35.0964
28	150	1	2.4249	34.7167	35.3185	34.8423	35.0996	34.8078
29	200	10	2.4116	34.7254	35.3401	34.8521	35.3705	34.7708
30	200	5	2.4047	34.9115	35.5464	35.0408	35.5816	34.983
31	200	20	2.4199	29.6582	30.2108	29.7854	30.039	29.6753
32	200	1	2.3813	29.6978	30.3156	29.8255	30.1291	29.7874
33	300	10	2.3989	29.7662	30.3813	29.8931	30.4141	29.821
34	300	1	2.4255	34.8715	35.4977	34.9984	35.1791	34.97
35	300	5	2.4324	34.9358	35.5622	35.0662	35.6006	35.0038
36	300	20	2.4177	34.7023	35.3259	34.8334	35.1984	34.7182
37	100	1	2.4147	29.7008	30.3184	29.8304	30.0925	29.7897
38	100	10	2.4066	34.8996	35.5376	35.0324	35.5322	34.9399
39	100	20	2.4621	34.9832	35.6129	35.1151	35.3294	34.9804
40	100	5	2.4594	29.7781	30.4126	29.9124	30.1946	29.8202
41	100	10	2.4189	34.6341	35.2809	34.7671	35.298	34.6959
42	100	5	2.4436	35.1626	35.7776	35.2883	35.794	35.23
43	100	20	2.4277	31.2304	31.8436	31.3584	31.463	31.2292
44	100	1	2.4654	35.0523	35.6733	35.1817	35.494	35.1432
45	300	10	2.4909	31.7176	32.3251	31.8425	32.1801	31.7448
46	300	20	2.4483	29.5681	30.1816	29.6923	30.1098	29.6005
47	300	5	2.3993	30.9359	31.5536	31.062	31.5957	30.9998
48	300	1	2.412	34.7482	35.3905	34.8831	35.2009	34.8415
49	50	5	2.422	34.9158	35.5841	35.0554	35.3984	34.9798
50	50	1	2.4164	35.1487	35.7879	35.2801	35.5448	35.2399

51	50	20	2.4005	29.7708	30.4273	29.9069	30.2289	29.7777
52	50	10	2.4097	35.226	35.8711	35.3588	35.3987	35.2236
53	150	1	2.458	30.0109	30.669	30.1476	30.4512	30.1089
54	150	20	2.4902	35.0476	35.6892	35.1807	35.5983	35.075
55	150	10	2.4303	29.7062	30.3463	29.8388	30.4992	29.7515
56	150	5	2.4245	31.7088	32.3311	31.8389	32.2163	31.7576
57	200	20	2.3982	34.6045	35.2432	34.7376	34.8189	34.6036
58	200	1	2.438	30.993	31.6375	31.1261	31.3156	31.0933
59	200	5	2.4177	34.942	35.5744	35.0737	35.611	35.0038
60	200	10	2.3766	34.0619	34.6616	34.1873	34.5767	34.0887

Table A.3. Raw data of the influence of the combination between sodium hydroxide and sodium hypochlorite.

No.	NaOH Conc., kg/m^3	NaClO Conc., ppm	Time, min	Plate, gram	Coupon, gram	Milk1, gram	Dry1, gram	Clean, gram	DryClean, gram
1	15	50	10	2.4516	34.7652	35.4117	34.9008	35.0484	34.777
2	15	50	5	2.4279	34.6734	35.315	34.8077	34.9931	34.7197
3	15	50	1	2.4353	31.2485	31.8771	31.3819	31.6034	31.3421
4	15	50	20	2.3946	29.7633	30.4234	29.9024	30.0083	29.7729
5	7.5	50	5	2.4505	34.8863	35.5042	35.0156	35.1556	34.9082
6	7.5	50	20	2.4141	34.8607	35.4953	34.9933	35.0589	34.8642
7	7.5	50	1	2.3976	34.5523	35.1974	34.6885	34.8348	34.6445
8	7.5	50	10	2.4273	34.8582	35.5057	34.9955	35.0838	34.8602
9	5	0	5	2.4467	34.8902	35.5118	35.017	35.117	34.9266
10	5	0	10	2.4344	29.709	30.3255	29.8333	29.849	29.714
11	5	0	1	2.4737	28.8285	29.4669	28.9589	29.1014	28.9226
12	5	0	20	2.4674	29.5864	30.2189	29.7167	29.7186	29.5861
13	15	150	5	2.4345	31.2374	31.8979	31.3775	31.5319	31.275
14	15	150	20	2.4235	31.3384	32.0036	31.4774	31.5563	31.344
15	15	150	1	2.4237	34.9996	35.6556	35.1371	35.4229	35.1035
16	15	150	10	2.4049	34.2442	34.869	34.3761	34.4497	34.2538
17	0	100	1	2.4648	34.6703	35.3109	34.8017	35.0531	34.7693
18	0	100	10	2.4094	34.9331	35.5774	35.0633	35.6879	34.9886
19	0	100	5	2.4109	34.7463	35.3636	34.8729	35.2981	34.8164
20	0	100	20	2.4547	30.9899	31.6278	31.1232	31.3579	31.0088

21	5	0	5	2.4718	30.022	30.6803	30.1557	30.1807	30.0547
22	5	0	10	2.3979	35.0538	35.6906	35.184	35.1852	35.0603
23	5	0	20	2.4699	35.1622	35.7955	35.2923	35.3218	35.161
24	5	0	1	2.4528	31.3638	31.992	31.493	31.6647	31.4466
25	5	50	10	2.4181	31.1079	31.6909	31.2287	31.2216	31.1096
26	5	50	5	2.4005	34.9034	35.5322	35.0343	35.0574	34.9223
27	5	50	1	2.4424	35.0287	35.6417	35.1555	35.3024	35.1147
28	5	50	20	2.4428	34.7277	35.3723	34.8623	34.9725	34.7299
29	0.5	200	10	2.4108	35.0667	35.6917	35.1929	35.3909	35.0888
30	0.5	200	20	2.4001	35.1174	35.7269	35.2436	35.3044	35.12
31	0.5	200	1	2.436	29.7504	30.3747	29.8811	30.2285	29.8459
32	0.5	200	5	2.4546	34.7474	35.3758	34.8792	35.201	34.7972
33	5	50	10	2.4487	34.8628	35.4931	34.9939	35.0223	34.8625
34	5	50	20	2.4465	35.1773	35.8066	35.3069	35.3707	35.1777
35	5	50	1	2.4405	35.1332	35.7771	35.2673	35.4043	35.2286
36	5	50	5	2.4223	30.9778	31.6158	31.1098	31.118	31.0026
37	5	150	10	2.4361	31.6616	32.2997	31.7944	31.8241	31.6635
38	5	150	1	2.403	29.7202	30.3495	29.8493	30.0634	29.8186
39	5	150	5	2.4511	31.7354	32.3267	31.857	31.9121	31.7526
40	5	150	20	2.468	34.8028	35.4295	34.9337	34.9868	34.8041
41	15	200	10	2.4222	34.1071	34.7356	34.2375	34.3298	34.1129
42	15	200	1	2.4404	34.6448	35.2788	34.7755	34.9814	34.7408
43	15	200	5	2.4398	34.9321	35.5804	35.0671	35.2058	34.9757
44	15	200	20	2.406	35.218	35.8529	35.349	35.3776	35.2223
45	0	150	10	2.4155	30.971	31.582	31.0992	31.6462	31.0223
46	0	150	5	2.4002	31.6269	32.2573	31.7569	32.2864	31.7036
47	0	150	20	2.4535	34.9746	35.5903	35.1014	35.6639	35.0157
48	0	150	1	2.4266	34.9195	35.5628	35.0538	35.3513	35.0196
49	5	200	20	2.4885	29.8582	30.5047	29.9945	30.0527	29.8589
50	5	200	5	2.5094	30.0622	30.7017	30.2009	30.3072	30.0954
51	5	200	1	2.4246	34.9478	35.5427	35.0767	35.2712	35.0383
52	5	200	10	2.4265	34.9833	35.6134	35.1139	35.1982	34.9858
53	7.5	100	10	2.5118	31.0474	31.6948	31.1827	31.1802	31.0482
54	7.5	100	1	2.4834	29.769	30.3995	29.9003	30.1461	29.8658
55	7.5	100	5	2.4791	29.7544	30.3857	29.8857	29.9773	29.7717
56	7.5	100	20	2.4711	29.5904	30.2315	29.7258	29.844	29.5938
57	0	0	10	2.4933	29.8092	30.4407	29.9427	30.313	29.8629
58	0	0	5	2.4413	34.6736	35.3096	34.8062	35.1023	34.7542
59	0	0	20	2.4113	34.096	34.7366	34.2281	34.2872	34.0937
60	0	0	1	2.4749	34.3143	34.9456	34.4478	34.6729	34.4096
61	15	0	10	2.4303	34.9549	35.5956	35.0889	35.0962	34.9608

62	15	0	1	2.4644	31.0188	31.6505	31.1497	31.3382	31.1202
63	15	0	5	2.4693	31.0038	31.6163	31.1298	31.2189	31.0396
64	15	0	20	2.458	31.6814	3.2764	31.8029	31.8171	31.6861
65	5	200	10	2.4088	34.9956	35.6062	35.1214	35.197	34.9969
66	5	200	5	2.4611	34.3008	34.9375	34.4314	34.549	34.3264
67	5	200	1	2.4411	34.8723	35.5223	35.0066	35.191	34.9692
68	5	200	20	2.4158	29.7309	30.3762	29.8653	29.9217	29.7313
69	7.5	200	10	2.3884	35.1062	35.7126	35.2313	35.2786	35.1101
70	7.5	200	1	2.4009	34.7141	35.3517	34.8468	35.0264	34.8112
71	7.5	200	5	2.4096	34.903	35.5157	35.0288	35.1321	34.9272
72	7.5	200	20	2.4447	31.2465	31.8747	31.3777	31.5017	31.2494
73	7.5	0	10	2.4241	34.916	35.562	35.0493	35.0666	34.9213
74	7.5	0	5	2.4619	35.1924	35.8211	35.3219	35.392	35.2267
75	7.5	0	1	2.4138	31.6975	32.3274	31.8273	32.0048	31.7939
76	7.5	0	20	2.4472	34.9386	35.5054	35.0539	35.1357	34.9412
77	0	50	20	2.4658	29.5855	30.2409	29.722	29.981	29.6147
78	0	50	10	2.4109	34.9687	35.6088	35.0996	35.6359	35.0305
79	0	50	5	2.4505	34.2892	34.9449	34.4247	34.7832	34.369
80	0	50	1	2.4121	34.0969	34.7496	34.2329	34.3986	34.1976
81	7.5	150	10	2.4165	34.9194	35.5693	35.0566	35.1014	34.922
82	7.5	150	5	2.4386	34.9592	35.6195	35.0958	35.2489	34.994
83	7.5	150	1	2.4195	34.9965	35.6423	35.131	35.2749	35.0907
84	7.5	150	20	2.4082	34.6512	35.3123	34.7914	34.8627	34.6531
85	0	100	1	2.4147	29.7008	30.3184	29.8304	30.0925	29.7897
86	0	100	10	2.4066	34.8996	35.5376	35.0324	35.5322	34.9399
87	0	100	20	2.4621	34.9832	35.6129	35.1151	35.3294	34.9804
88	0	100	5	2.4594	29.7781	30.4126	29.9124	30.1946	29.8202
89	7.5	200	5	2.4351	34.7188	35.3477	34.8485	34.9634	34.7355
90	7.5	200	10	2.4323	34.9394	35.5598	35.0669	35.1484	34.9427
91	7.5	200	1	2.3931	34.8291	35.4691	34.9622	35.1971	34.926
92	7.5	200	20	2.3858	31.0758	31.7372	31.2142	31.24	31.0778
93	7.5	50	5	2.3841	34.5391	35.1584	34.6693	34.7688	34.5598
94	7.5	50	10	2.4187	35.074	35.7125	35.2054	35.3251	35.0791
95	7.5	50	20	2.4074	31.3213	31.9415	31.449	31.5766	31.3254
96	7.5	50	1	2.3867	34.8325	35.4505	34.96	35.1276	34.921
97	5	150	5	2.4534	34.6585	35.2826	34.7879	34.9506	34.6854
98	5	150	20	2.4572	29.8262	30.4422	29.9524	30.0828	29.8275
99	5	150	1	2.4341	34.7689	35.3861	34.8965	35.1138	34.862
100	5	150	10	2.442	34.1278	34.7592	34.2596	34.3141	34.1284
101	0.5	150	10	2.4707	34.9926	35.6303	35.1254	35.372	35.0205
102	0.5	150	5	2.4639	29.5838	30.2424	29.7208	29.9885	29.653

103	0.5	150	1	2.458	29.8279	30.4916	29.9663	30.2788	29.9347
104	0.5	150	20	2.466	31.7493	32.4305	31.8917	31.9819	31.7511
105	0.5	200	10	2.4505	31.6755	32.2993	31.805	32.0943	31.7049
106	0.5	200	20	2.4177	34.8319	35.4486	34.9576	35.1606	34.8368
107	0.5	200	5	2.4397	35.1313	35.7771	35.2647	35.7455	35.2019
108	0.5	200	1	2.4549	35.1863	35.785	35.3118	35.5985	35.276
109	15	50	20	2.4353	34.4063	35.0356	34.5376	34.6314	34.4127
110	15	50	5	2.439	34.9968	35.6292	35.1272	35.3045	35.0294
111	15	50	1	2.4053	29.6922	30.3263	29.8243	30.0836	29.7917
112	15	50	10	2.3847	34.6766	35.3191	34.8132	34.932	34.695
113	15	150	10	2.4369	34.9302	35.5728	35.0654	35.3544	34.9606
114	15	150	5	2.4097	35.2102	35.8255	35.337	35.3676	35.2236
115	15	150	1	2.422	30.9563	31.588	31.0889	31.2781	31.0503
116	15	150	20	2.4273	31.2411	31.8417	31.3668	31.4623	31.2512
117	7.5	150	5	2.445	29.9977	30.6585	30.1375	30.3029	30.0287
118	7.5	150	20	2.4221	29.6975	30.3407	29.8311	29.894	29.6983
119	7.5	150	1	2.3905	30.9457	31.5749	31.076	31.2547	31.0386
120	7.5	150	10	2.4526	29.7701	30.383	29.8978	29.9499	29.7711
121	0.5	0	5	2.468	34.6733	35.28	34.8011	35.007	34.7335
122	0.5	0	10	2.4191	34.9402	35.5138	35.0582	35.295	34.971
123	0.5	0	20	2.4305	34.7441	35.3897	34.8791	34.9628	34.7474
124	0.5	0	1	2.4053	34.7409	35.3621	34.8726	35.164	34.8315
125	5	0	20	2.4627	29.8319	30.4428	29.9546	30.0686	29.8316
126	5	0	1	2.4684	29.7835	30.4044	29.91	30.0732	29.8789
127	5	0	10	2.4172	34.9243	35.5631	35.0549	35.0855	34.9346
128	5	0	5	2.4685	35.125	35.757	35.2561	35.3682	35.1518
129	0.5	100	20	2.4141	31.1021	31.7357	31.2337	31.3326	31.1042
130	0.5	100	1	2.4316	34.7249	35.3663	34.8573	35.2517	34.8247
131	0.5	100	5	2.4501	29.7369	30.3523	29.8643	30.1466	29.7926
132	0.5	100	10	2.4425	34.937	35.573	35.0689	35.28	34.9643
133	15	100	5	2.409	34.9031	35.5368	35.0357	35.0799	34.9309
134	15	100	1	2.4199	34.6262	35.2786	34.7608	35.0003	34.7247
135	15	100	20	2.4198	35.1394	35.8025	35.2777	35.293	35.1467
136	15	100	10	2.4215	30.9574	31.5949	31.0915	31.1139	30.9717
137	15	50	20	2.4425	34.9466	35.608	35.0848	35.1224	34.9535
138	15	50	5	2.4676	34.914	35.5738	35.0507	35.1737	34.9553
139	15	50	10	2.4696	29.8393	30.4964	29.9751	30.0742	29.8454
140	15	50	1	2.4206	31.2348	31.8896	31.3701	31.6054	31.3316
141	0.5	150	5	2.4541	34.6974	35.3428	34.8334	35.1385	34.7518
142	0.5	150	1	2.4246	34.709	35.3626	34.8446	35.1866	34.8143
143	0.5	150	10	2.434	35.0897	35.7646	35.2317	35.5046	35.1295

144	0.5	150	20	2.4386	34.1239	34.7794	34.2631	34.3595	34.1252
145	0	200	5	2.4084	29.7793	30.4033	29.9062	30.2408	29.8369
146	0	200	10	2.4306	29.7061	30.3391	29.831	30.3815	29.77
147	0	200	1	2.4491	35.1803	35.8194	35.3079	35.4812	35.2844
148	0	200	20	2.376	31.6607	32.2742	31.7868	32.0379	31.6794
149	0	150	5	2.3977	34.8335	35.4452	34.9613	35.4695	34.8966
150	0	150	10	2.404	35.0964	35.7084	35.2221	35.7791	35.1556
151	0	150	20	2.4053	35.0607	35.6761	35.188	35.7702	35.0964
152	0	150	1	2.4249	34.7167	35.3185	34.8423	35.0996	34.8078
153	0	150	1	2.458	30.0109	30.669	30.1476	30.4512	30.1089
154	0	150	20	2.4902	35.0476	35.6892	35.1807	35.5983	35.075
155	0	150	10	2.4303	29.7062	30.3463	29.8388	30.4992	29.7515
156	0	150	5	2.4245	31.7088	32.3311	31.8389	32.2163	31.7576
157	0	0	10	2.424	31.2377	31.8547	31.3646	31.7754	31.2945
158	0	0	1	2.3873	34.8967	35.4966	35.0177	35.344	34.9908
159	0	0	5	2.4634	35.1563	35.7564	35.2809	35.577	35.2285
160	0	0	20	2.4413	34.7547	35.3507	34.8769	35.0966	34.7662
161	15	150	5	2.4136	34.2526	34.9045	34.3907	34.6218	34.3132
162	15	150	1	2.4441	34.8813	35.526	35.0166	35.2468	34.9919
163	15	150	10	2.4771	31.2806	31.917	31.4127	31.5699	31.2908
164	15	150	20	2.4567	34.6124	35.255	34.7471	34.7432	34.6152
165	0	100	10	2.4789	34.6341	35.2809	34.7671	35.298	34.6959
166	0	100	5	2.4436	35.1626	35.7776	35.2883	35.794	35.23
167	0	100	20	2.4277	31.2304	31.8436	31.3584	31.463	31.2292
168	0	100	1	2.4654	35.0523	35.6733	35.1817	35.494	35.1432
169	15	200	5	2.453	35.1453	35.8003	35.2843	35.591	35.2049
170	15	200	20	2.4522	29.5712	30.2381	29.7117	29.7791	29.5809
171	15	200	10	2.4777	31.3912	32.0447	31.5277	31.6119	31.407
172	15	200	1	2.4627	31.748	32.378	31.8792	32.1157	31.8495
173	7.5	150	20	2.453	35.0111	35.6702	35.151	35.267	35.0142
174	7.5	150	5	2.5053	35.0833	35.7398	35.2206	35.3801	35.1104
175	7.5	150	10	2.4997	31.7255	32.3964	31.8659	31.8655	31.7268
176	7.5	150	1	2.4547	34.8691	35.5228	35.0068	35.2737	34.9655
177	5	200	5	2.4656	29.7036	30.3784	29.8462	29.9045	29.729
178	5	200	1	2.4621	29.7765	30.435	29.9131	30.1296	29.8781
179	5	200	20	2.4051	34.7185	35.3732	34.8555	34.9967	34.7216
180	5	200	10	2.4274	35.156	35.8072	35.2938	35.3778	35.1599
181	15	100	10	2.4124	34.9201	35.5663	35.0566	35.4653	34.957
182	15	100	5	2.4616	34.7973	35.4464	34.9341	35.1387	34.8389
183	15	100	1	2.4425	34.9633	35.6013	35.0981	35.322	35.0634
184	15	100	20	2.4743	29.8436	30.5107	29.9847	30.0369	29.8493

185	5	150	1	2.4464	35.0334	35.6934	35.1725	35.3923	35.1338
186	5	150	20	2.4402	34.9625	35.6413	35.107	35.231	34.9657
187	5	150	10	2.4415	35.2171	35.8673	35.3505	35.3834	35.2175
188	5	150	5	2.4818	31.0372	31.7052	31.1775	31.3242	31.0694
189	15	0	5	2.4696	34.4306	35.0318	34.5519	34.6245	34.4682
190	15	0	20	2.4775	35.0521	35.6865	35.1811	35.2222	35.0577
191	15	0	10	2.4531	31.2569	31.8817	31.3845	31.4455	31.2634
192	15	0	1	2.467	29.7034	30.3133	29.8302	29.9923	29.7999
193	0	50	5	2.4426	34.8564	35.4724	34.9836	35.2914	34.9176
194	0	50	10	2.4137	31.106	31.7213	31.2321	31.6613	31.1585
195	0	50	1	2.4425	34.4127	35.0026	34.5334	34.7305	34.5021
196	0	50	20	2.413	34.9891	35.5753	35.1108	35.2389	34.9884
197	7.5	200	10	2.4859	34.7698	35.3785	34.8948	34.9573	34.7724
198	7.5	200	5	2.4897	29.8585	30.4767	29.9856	30.1015	29.885
199	7.5	200	20	2.4809	35.2034	35.8077	35.327	35.4182	35.2063
200	7.5	200	1	2.4655	34.6212	35.2448	34.7504	34.9027	34.7167
201	0	200	10	2.4116	34.7254	35.3401	34.8521	35.3705	34.7708
202	0	200	5	2.4047	34.9115	35.5464	35.0408	35.5816	34.983
203	0	200	20	2.4199	29.6582	30.2108	29.7854	30.039	29.6753
204	0	200	1	2.3813	29.6978	30.3156	29.8255	30.1291	29.7874
205	0.5	0	20	2.4427	35.0006	35.6077	35.1268	35.3768	35.0065
206	0.5	0	5	2.4794	29.765	30.3768	29.8913	30.0838	29.8247
207	0.5	0	1	2.4454	29.8145	30.4424	29.9421	30.2014	29.9047
208	0.5	0	10	2.4418	34.9496	35.568	35.0766	35.1949	34.9741
209	15	0	1	2.4701	34.3079	34.9289	34.4338	34.5993	34.4039
210	15	0	10	2.4155	35.1088	35.7379	35.236	35.2182	35.1152
211	15	0	20	2.4179	31.3296	31.9618	31.4593	31.4773	31.3318
212	15	0	5	2.4785	34.7913	35.4195	34.9206	34.9887	34.8189
213	7.5	100	1	2.441	34.755	35.4231	34.8945	35.0978	34.8602
214	7.5	100	10	2.4407	34.963	35.6216	35.0997	35.1793	34.9668
215	7.5	100	5	2.4507	34.7435	35.3651	34.8719	35.0063	34.7667
216	7.5	100	20	2.4194	31.2337	31.8957	31.3729	31.4637	31.2366
217	15	200	1	2.431	34.9262	35.546	35.0555	35.2389	35.0189
218	15	200	10	2.4376	29.7529	30.4132	29.8896	29.9725	29.7612
219	15	200	20	2.3973	34.6041	35.2493	34.7387	34.9701	34.6129
220	15	200	5	2.437	35.1305	35.7824	35.2677	35.4891	35.1712
221	7.5	50	20	2.4124	34.9063	35.5789	35.0483	35.1137	34.9105
222	7.5	50	5	2.4187	34.9268	35.5743	35.0604	35.1786	34.9566
223	7.5	50	1	2.406	29.5272	30.1649	29.6598	30.0061	29.6268
224	7.5	50	10	2.3942	31.3086	31.9541	31.4437	31.5111	31.3108
225	0	50	5	2.422	34.9158	35.5841	35.0554	35.3984	34.9798

226	0	50	1	2.4164	35.1487	35.7879	35.2801	35.5448	35.2399
227	0	50	20	2.4005	29.7708	30.4273	29.9069	30.2289	29.7777
228	0	50	10	2.4097	35.226	35.8711	35.3588	35.3987	35.2236
229	0.5	150	5	2.3765	31.6607	32.276	31.7902	32.1008	31.7076
230	0.5	150	1	2.4149	35.1878	35.8348	35.3226	35.5767	35.2883
231	0.5	150	20	2.4315	34.8713	35.5273	35.0084	35.1363	34.8766
232	0.5	150	10	2.4205	34.9789	35.6466	35.1183	35.3369	35.0081
233	0.5	50	20	2.4312	34.7674	35.4215	34.9052	34.9882	34.7683
234	0.5	50	1	2.3986	34.0839	34.7034	34.2136	34.6115	34.1786
235	0.5	50	5	2.4064	34.9107	35.5515	35.0448	35.3918	34.9746
236	0.5	50	10	2.4165	34.8473	35.5167	34.9877	35.2678	34.8878
237	0	0	5	2.4431	34.8574	35.482	34.9853	35.3976	34.9328
238	0	0	20	2.4271	34.8591	35.4604	34.981	35.4225	34.9022
239	0	0	10	2.4095	29.7782	30.3875	29.9036	30.2563	29.8348
240	0	0	1	2.4166	29.7323	30.3575	29.8629	30.0795	29.8278
241	0.5	0	10	2.4171	35.1346	35.7397	35.2598	35.4394	35.1542
242	0.5	0	20	2.4051	35.0606	35.6759	35.1853	35.4462	35.0689
243	0.5	0	5	2.592	34.7523	35.3591	34.8755	35.162	34.8031
244	0.5	0	1	2.4258	34.5817	35.1795	34.7053	34.8858	34.6689
245	0.5	50	1	2.4607	34.3037	34.9609	34.4419	34.7412	34.4055
246	0.5	50	5	2.4373	35.0932	35.7649	35.2328	35.5154	35.1642
247	0.5	50	10	2.5213	31.325	31.9774	31.4599	31.69	31.355
248	0.5	50	20	2.46	35.0376	35.6959	35.1757	35.249	35.0384
249	7.5	100	1	2.4996	35.0875	35.7407	35.2243	35.467	35.1875
250	7.5	100	10	2.4321	35.1633	35.8236	35.3007	35.3478	35.166
251	7.5	100	5	2.4212	29.7073	30.3701	29.8452	30.0119	29.7364
252	7.5	100	20	2.4161	31.6412	32.2902	31.7765	31.9151	31.6444
253	0.5	200	20	2.3939	30.9298	31.5983	31.0694	31.2227	30.9435
254	0.5	200	5	2.3894	34.6321	35.2845	34.7668	35.0748	34.7091
255	0.5	200	10	2.4292	34.9523	35.6124	35.0907	35.2971	34.9877
256	0.5	200	1	2.4248	34.8388	35.4817	34.9729	35.2586	34.9415
257	7.5	0	20	2.4545	34.1395	34.7611	34.2632	34.3169	34.1415
258	7.5	0	10	2.469	31.0041	31.6261	31.1288	31.175	31.0111
259	7.5	0	5	2.4639	34.7973	35.4178	34.9178	35.0643	34.8184
260	7.5	0	1	2.4156	34.908	35.5375	35.0368	35.2402	35.0018
261	5	100	5	2.4298	29.7046	30.3669	29.8411	29.9443	29.7478
262	5	100	10	2.4512	30.0028	30.6717	30.1397	30.2094	30.0096
263	5	100	20	2.4415	34.8891	35.5568	35.0287	35.1141	34.8913
264	5	100	1	2.4529	31.141	31.775	31.2727	31.5407	31.2374
265	7.5	0	5	2.4291	31.2329	31.8663	31.3608	31.4434	31.2731
266	7.5	0	20	2.4164	34.9926	35.5847	35.1134	35.2263	34.9955

267	7.5	0	1	2.4385	34.7367	35.3629	34.852	35.0313	34.8202
268	7.5	0	10	2.4403	35.0267	35.6606	35.1584	35.2415	35.0307
269	0.5	50	20	2.4723	34.975	35.6159	35.106	35.2755	34.9789
270	0.5	50	1	2.4338	34.119	34.7331	34.2444	34.5961	34.2143
271	0.5	50	10	2.4402	34.6818	35.314	34.8123	35.0769	34.7152
272	0.5	50	5	2.4714	30.0221	30.66	30.1551	30.3722	30.0788
273	0	200	20	2.3982	34.6045	35.2432	34.7376	34.8189	34.6036
274	0	200	1	2.438	30.993	31.6375	31.1261	31.3156	31.0933
275	0	200	5	2.4177	34.942	35.5744	35.0737	35.611	35.0038
276	0	200	10	2.3766	34.0619	34.6616	34.1873	34.5767	34.0887
277	0.5	100	1	2.3979	34.918	35.5483	35.0486	35.2769	35.0119
278	0.5	100	10	2.3892	34.3603	35.0213	34.496	34.7579	34.4011
279	0.5	100	20	2.4046	29.7732	30.4354	29.9101	30.055	29.7785
280	0.5	100	5	2.4194	30.9745	31.5903	31.1026	31.2302	31.0192
281	15	100	1	2.4543	31.3667	32.0089	31.5011	31.7864	31.4668
282	15	100	20	2.4519	35.183	35.8337	35.3174	35.4052	35.1874
283	15	100	10	2.4186	34.856	35.5236	34.9953	35.3831	34.8834
284	15	100	5	2.4162	34.9742	35.5765	35.1001	35.3176	35.0061
285	5	50	1	2.4309	35.0085	35.6405	35.1396	35.4409	35.1067
286	5	50	5	2.4426	34.8574	35.5149	34.9936	35.0876	34.8885
287	5	50	10	2.4285	34.7641	35.4214	34.9014	34.9968	34.7675
288	5	50	20	2.4211	34.9431	35.6029	35.0817	35.1823	34.946
289	5	100	20	2.431	31.1178	31.7557	31.2497	31.3466	31.1195
290	5	100	10	2.4444	34.727	35.3429	34.8542	34.9956	34.7299
291	5	100	5	2.4462	29.7202	30.3584	29.8541	29.9396	29.74
292	5	100	1	2.4645	29.5854	30.2443	29.7236	29.9189	29.685
293	0.5	100	10	2.4936	29.8082	30.4501	29.9422	30.0612	29.8111
294	0.5	100	5	2.4864	34.8002	35.4163	34.9263	35.2537	34.8572
295	0.5	100	1	2.4759	29.7618	30.3988	29.8945	30.1994	29.8557
296	0.5	100	20	2.4458	31.0606	31.6849	31.1916	31.2536	31.0625
297	5	100	20	2.4573	34.9535	35.5655	35.0781	35.2232	34.9557
298	5	100	5	2.4324	35.1545	35.7852	35.2824	35.4921	35.1857
299	5	100	10	2.4401	34.8718	35.5117	35.0032	35.1175	34.873
300	5	100	1	2.457	31.6827	32.3202	31.8156	32.0338	31.7776

* The data of 0 kg/m^3 of sodium hydroxide and 0 ppm of sodium hypochlorite was retrieved from Table A.1. and Table A.2., respectively.

The data from Table A.1., Table A.2., and Table A.3. was then handled to get the initial amount of fouling and the amount of fouling left on the coupon after cleaning. The initial amount of fouling for each coupon can be calculated by subtracting Dry1 column and Coupon column. The amount of fouling left on the coupon after cleaning is obtained by subtracting the DryClean column and Coupon column. The raw data can be represented in Figure A.1.

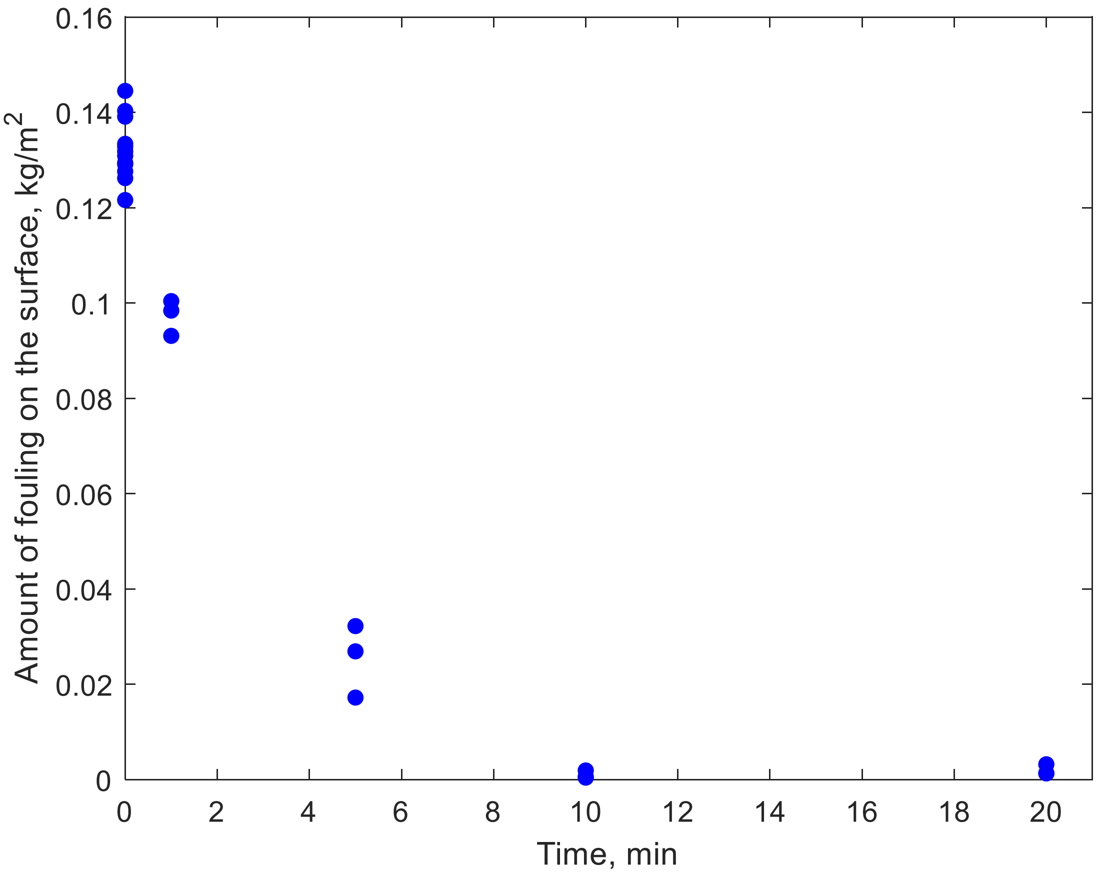

Figure A.1. Example of the raw data plot for 5 kg/m^3 NaOH vs 100 ppm NaClO.

Table A.4. Reproducibility of cleaning solution used in experiment

NaOH Conc., kg/m^3	NaClO Conc., ppm	Cond Avg, mS/cm	Cond S.D, mS/cm	pH Avg	pH S.D	TA Avg	TA S.D
0	0	0.01	0.01	7.48	1.93	n.d.	n.d.
0	50	0.20	0.01	9.48	0.04	n.d.	n.d.
0	100	0.39	0.02	10.04	0.13	n.d.	n.d.
0	150	0.58	0.03	10.35	0.03	n.d.	n.d.
0	200	0.77	0.04	10.47	0.01	n.d.	n.d.
0.5	0	2.43	0.22	12.01	0.03	0.04%	0.0037%
0.5	50	2.55	0.05	12.12	0.11	0.04%	0.0024%
0.5	100	2.77	0.04	12.24	0.21	0.04%	0.0014%
0.5	150	2.93	0.04	12.01	0.13	0.05%	0.0028%
0.5	200	3.03	0.29	12.03	0.13	0.05%	0.0014%
5	0	22.38	0.74	12.94	0.09	0.34%	0.0393%
5	50	20.75	2.23	13.10	0.23	0.35%	0.0037%
5	100	22.21	0.18	13.17	0.09	0.36%	0.0028%
5	150	22.37	0.17	12.98	0.12	0.35%	0.0037%
5	200	22.64	0.32	13.10	0.16	0.35%	0.0028%
7.5	0	33.33	1.10	13.02	0.03	0.51%	0.0254%
7.5	50	30.89	3.23	13.16	0.21	0.53%	0.0014%
7.5	100	32.93	0.15	13.22	0.22	0.53%	0.0088%
7.5	150	32.67	0.21	13.20	0.12	0.53%	0.0028%
7.5	200	32.73	0.55	13.31	0.04	0.53%	0.0037%
15	0	65.27	2.57	13.35	0.14	1.02%	0.0835%
15	50	58.47	5.38	13.39	0.12	1.05%	0.0042%
15	100	61.70	0.75	13.37	0.29	1.05%	0.0042%
15	150	58.60	5.39	13.36	0.07	1.05%	0.0028%
15	200	62.47	0.40	13.39	0.21	1.05%	0.0028%

Table A.5. ANOVA table of the 5 factors (after removing quadratic term of sodium hypochlorite concentration).

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	0.00024313	0.000061	51.5904
Error	70	0.00008247	1.18E-06	**Prob > F**
C. Total	74	0.0003256		<.0001*

Table A.6. Parameter estimates of each effect of ANOVA with 5 factors (after removing quadratic term of sodium hypochlorite concentration).

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.00381	0.000257	-14.79	<.0001*
NaOH	-0.00037	0.000029	-12.85	<.0001*
NaClO	-1.71E-06	1.77E-06	-0.96	0.3388
(NaOH-5.6)*(NaClO-100)	1.17E-07	3.24E-07	0.36	0.7196
(NaOH-5.6)*(NaOH-5.6)	6.45E-05	0.000005	12.87	<.0001*

Table A.7. ANOVA table of the 4 factors (after removing quadratic term of sodium hypochlorite concentration and cross-interaction effect).

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.00024298	0.000081	69.5967
Error	71	0.00008263	1.16E-06	**Prob > F**
C. Total	74	0.0003256		<.0001*

Table A.8. Parameter estimates of each effect of ANOVA 4 factors (after removing quadratic term of sodium hypochlorite concentration and cross-interaction effect).

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.003805	0.000256	-14.88	<.0001*
NaOH	-0.000372	2.88E-05	-12.93	<.0001*
NaClO	-1.71E-06	1.76E-06	-0.97	0.3358
(NaOH-5.6)*(NaOH-5.6)	0.0000645	4.98E-06	12.95	<.0001*

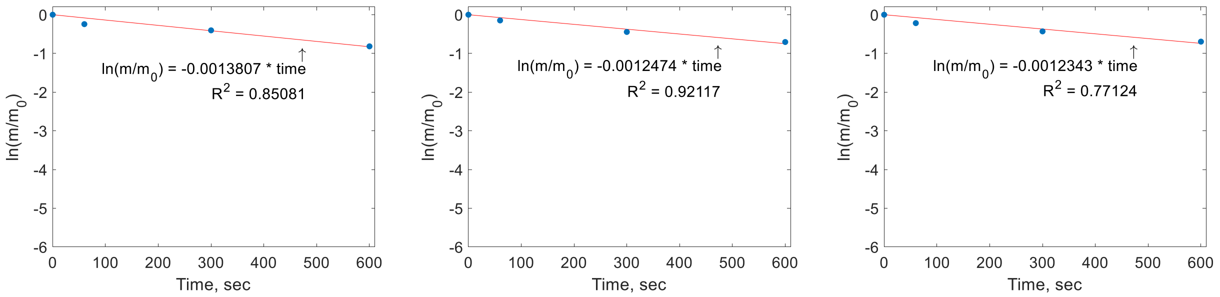

Figure A.2. First-order kinetic model for 0 kg/m^3 of sodium hydroxide and 0 ppm of sodium hypochlorite.

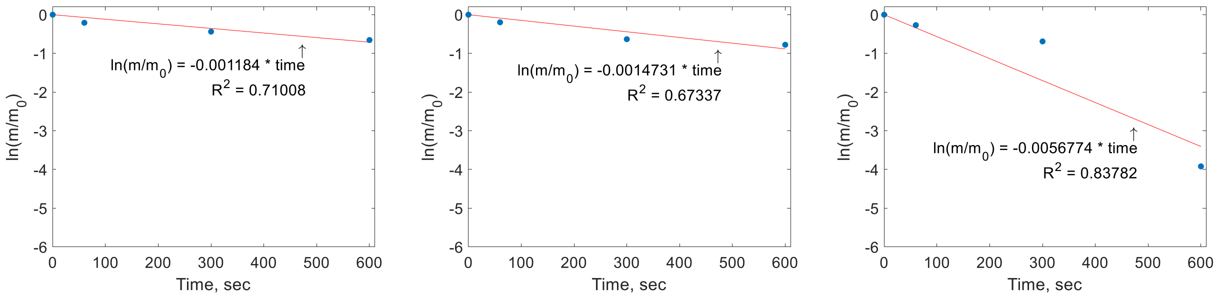

Figure A.3. First-order kinetic model for 0 kg/m^3 of sodium hydroxide and 50 ppm of sodium hypochlorite.

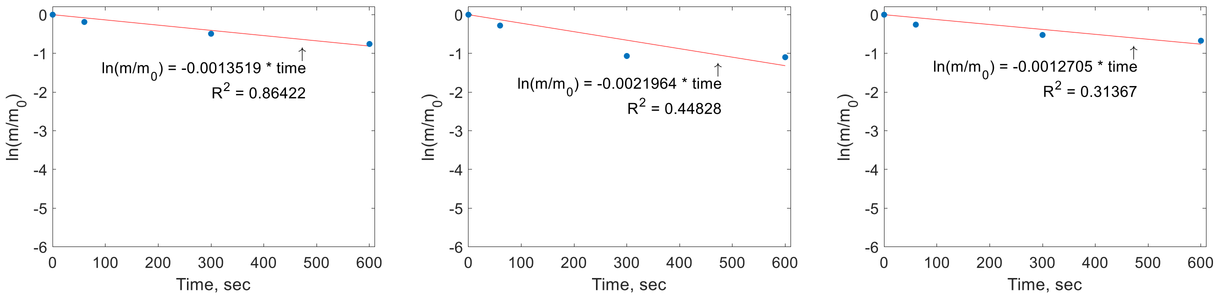

Figure A.4. First-order kinetic model for 0 kg/m^3 of sodium hydroxide and 100 ppm of sodium hypochlorite.

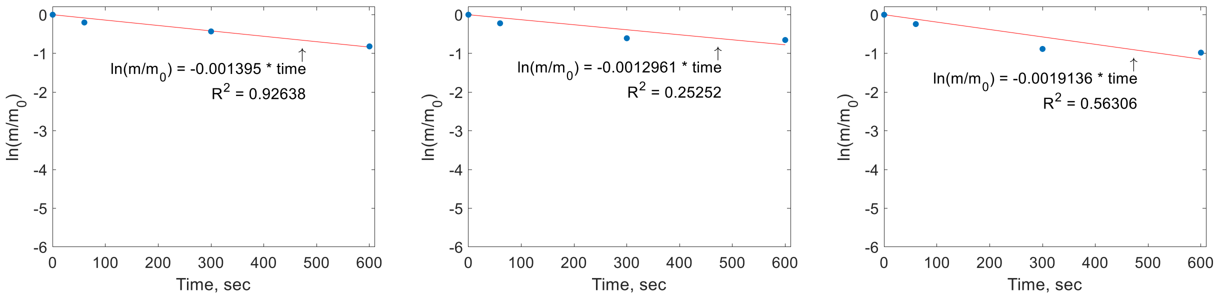

Figure A.5. First-order kinetic model for 0 kg/m^3 of sodium hydroxide and 150 ppm of sodium hypochlorite.

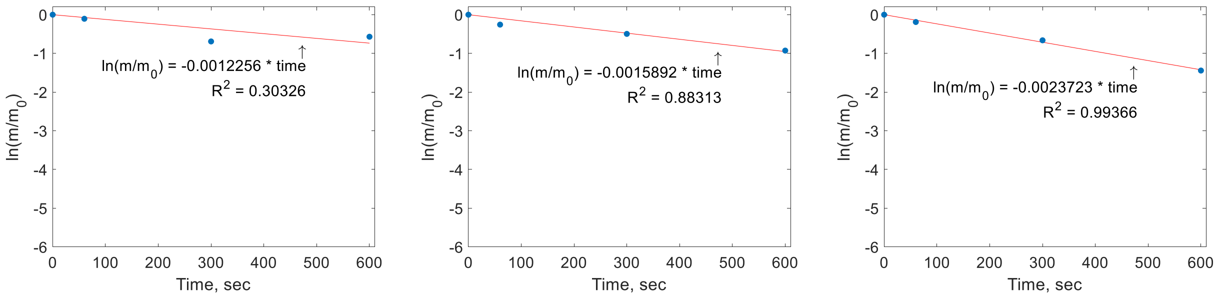

Figure A.6. First-order kinetic model for 0 kg/m^3 of sodium hydroxide and 200 ppm of sodium hypochlorite.

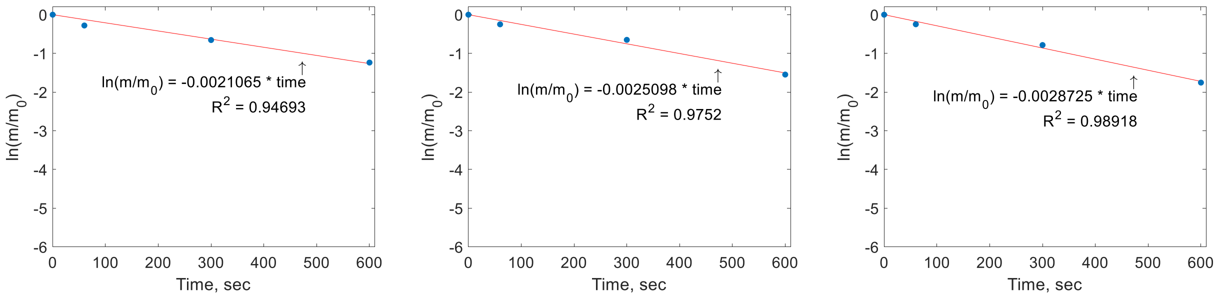

Figure A.7. First-order kinetic model for 0.5 kg/m^3 of sodium hydroxide and 0 ppm of sodium hypochlorite.

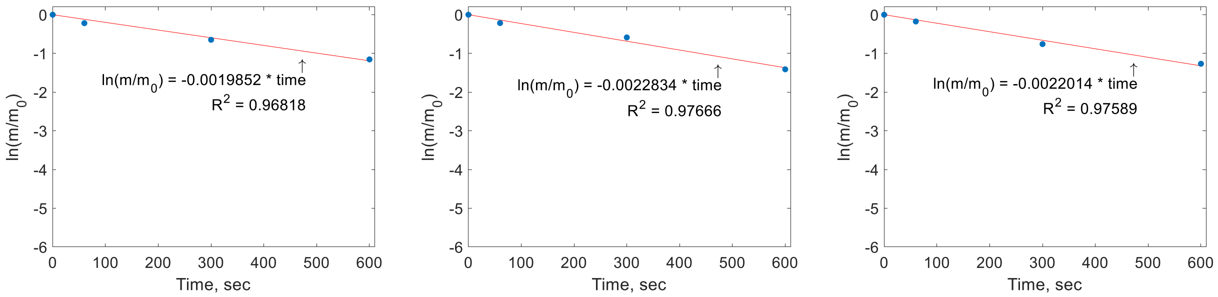

Figure A.8. First-order kinetic model for 0.5 kg/m^3 of sodium hydroxide and 50 ppm of sodium hypochlorite.

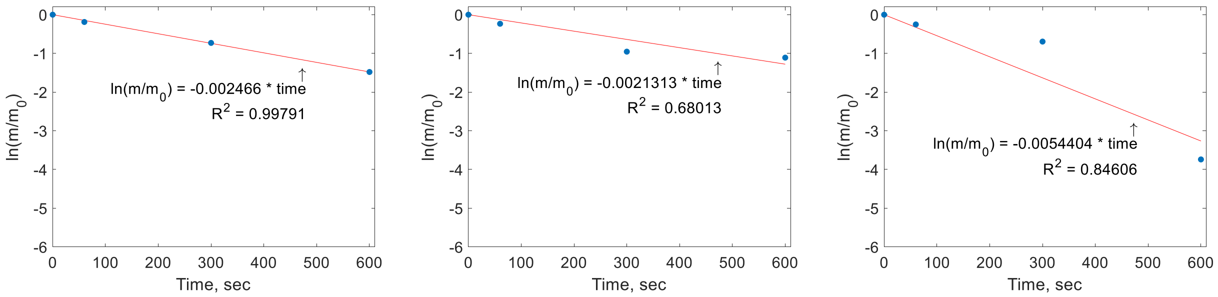

Figure A.9. First-order kinetic model for 0.5 kg/m^3 of sodium hydroxide and 100 ppm of sodium hypochlorite.

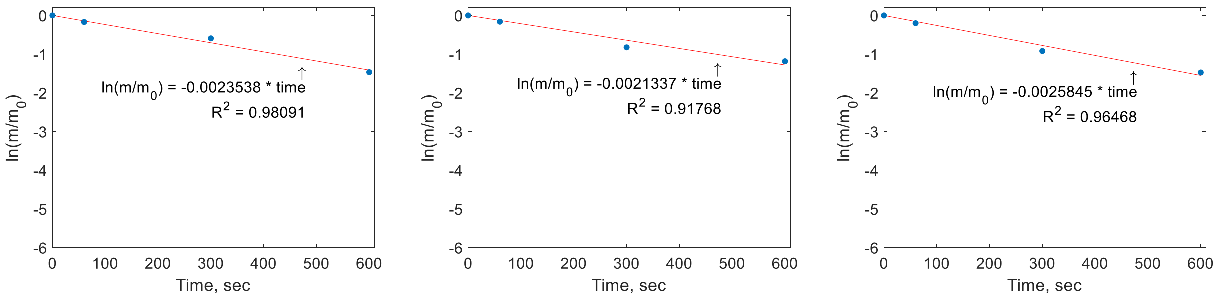

Figure A.10. First-order kinetic model for 0.5 kg/m^3 of sodium hydroxide and 150 ppm of sodium hypochlorite.

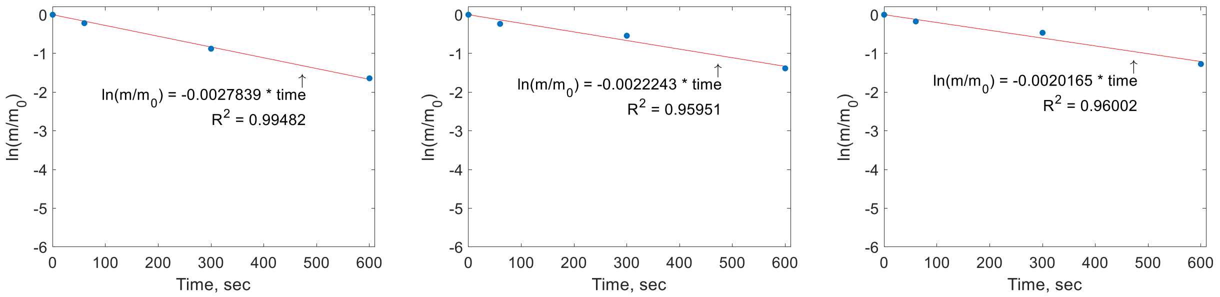

Figure A.11. First-order kinetic model for 0.5 kg/m^3 of sodium hydroxide and 200 ppm of sodium hypochlorite.

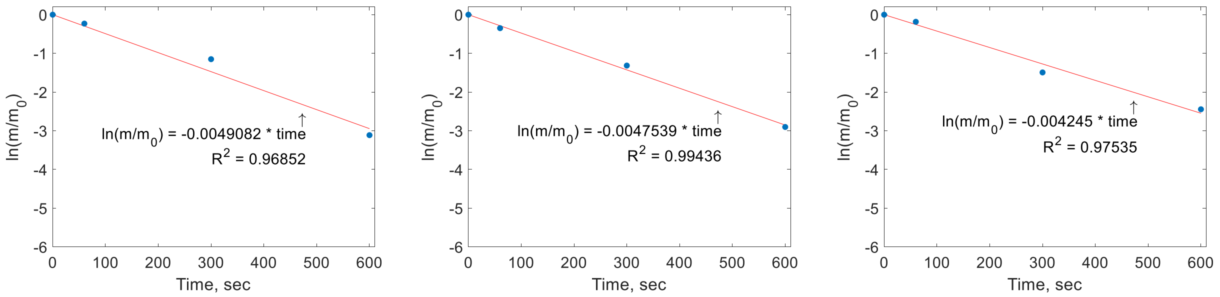

Figure A.12. First-order kinetic model for 5 kg/m^3 of sodium hydroxide and 0 ppm of sodium hypochlorite.

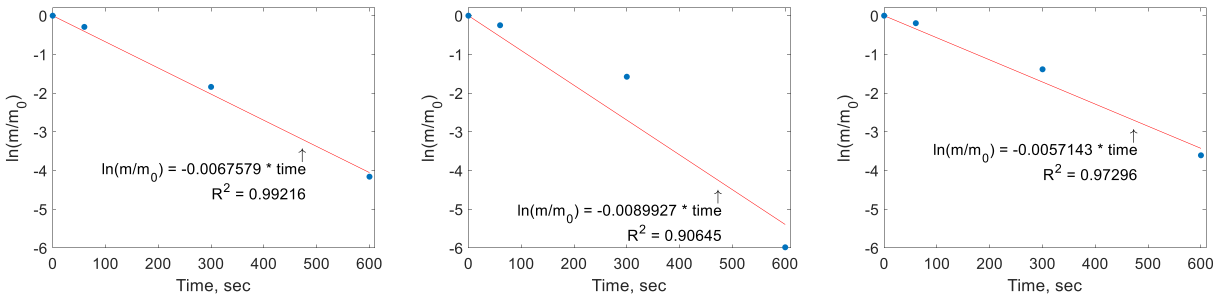

Figure A.13. First-order kinetic model for 5 kg/m^3 of sodium hydroxide and 50 ppm of sodium hypochlorite.

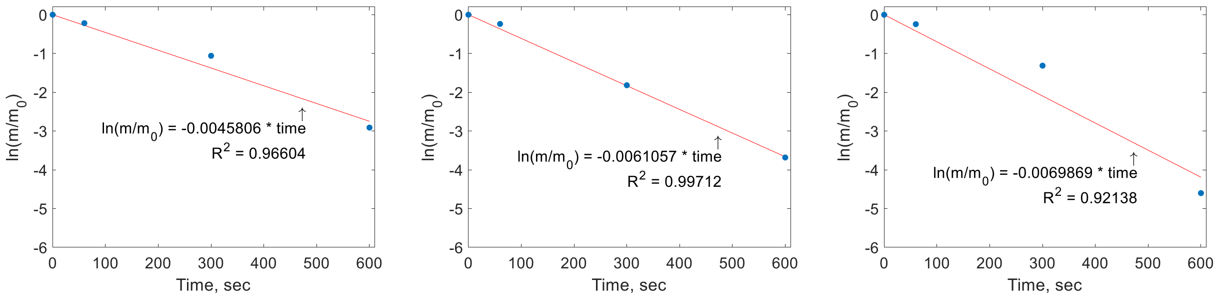

Figure A.14. First-order kinetic model for 5 kg/m^3 of sodium hydroxide and 100 ppm of sodium hypochlorite.

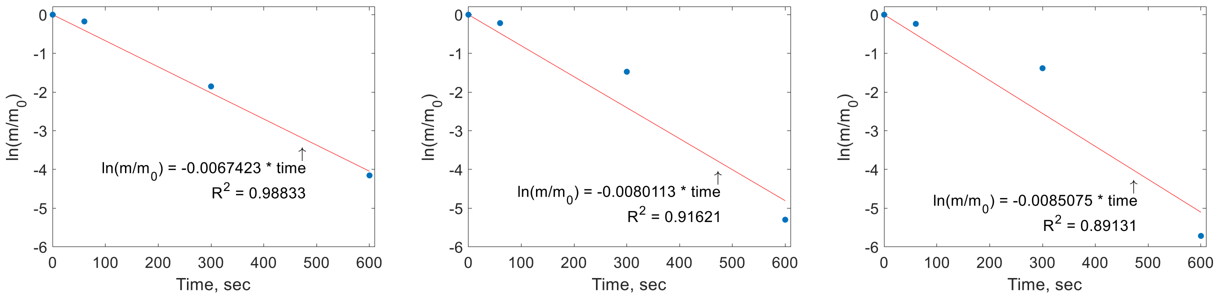

Figure A.15. First-order kinetic model for 5 kg/m^3 of sodium hydroxide and 150 ppm of sodium hypochlorite.

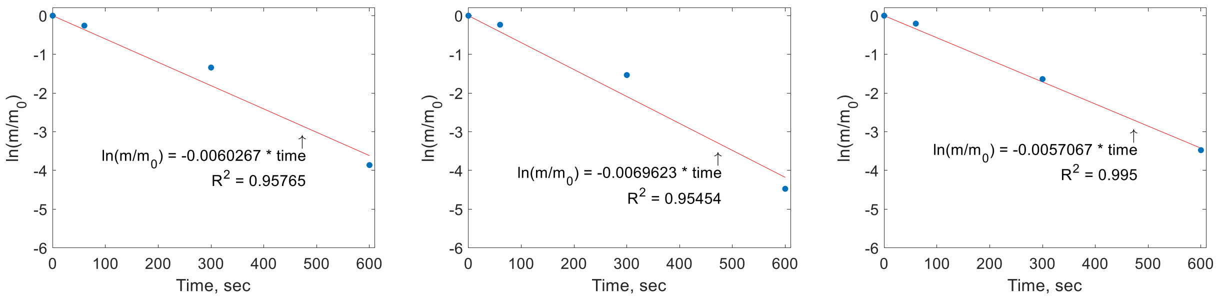

Figure A.16. First-order kinetic model for 5 kg/m^3 of sodium hydroxide and 200 ppm of sodium hypochlorite.

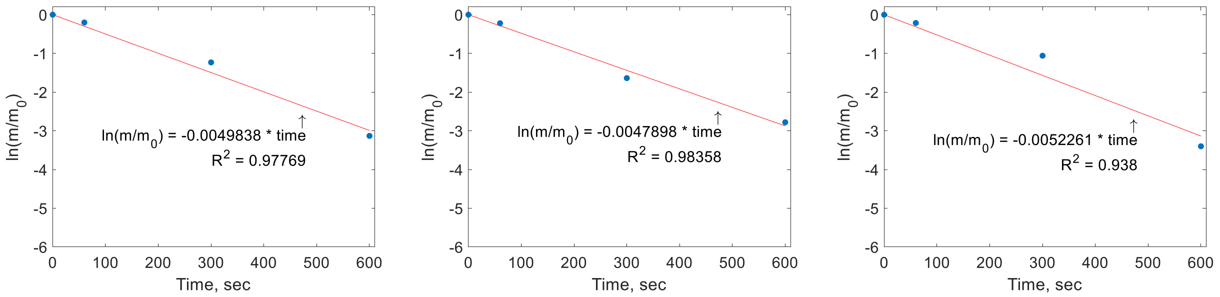

Figure A.17. First-order kinetic model for 7.5 kg/m^3 of sodium hydroxide and 0 ppm of sodium hypochlorite.

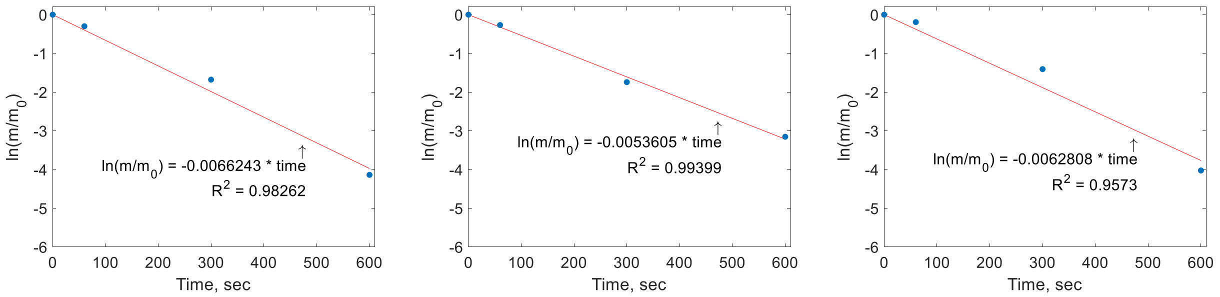

Figure A.18. First-order kinetic model for 7.5 kg/m^3 of sodium hydroxide and 50 ppm of sodium hypochlorite.

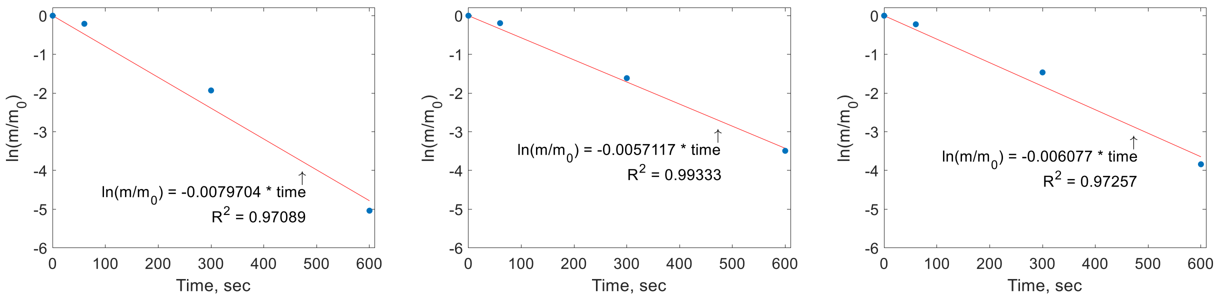

Figure A.19. First-order kinetic model for 7.5 kg/m^3 of sodium hydroxide and 100 ppm of sodium hypochlorite.

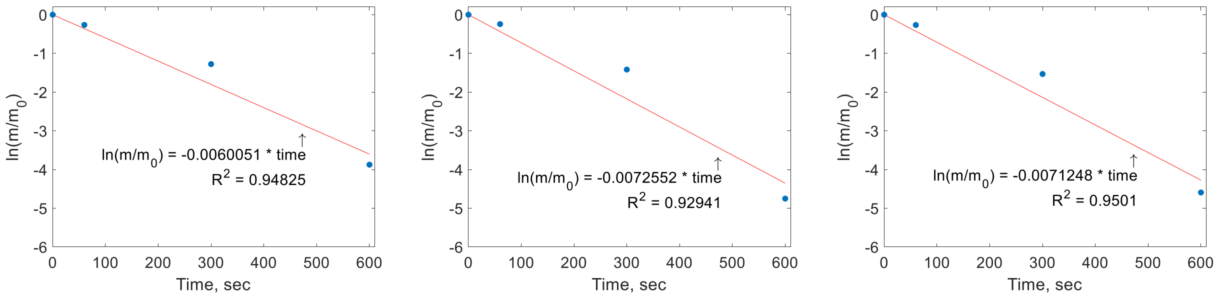

Figure A.20. First-order kinetic model for 7.5 kg/m^3 of sodium hydroxide and 150 ppm of sodium hypochlorite.

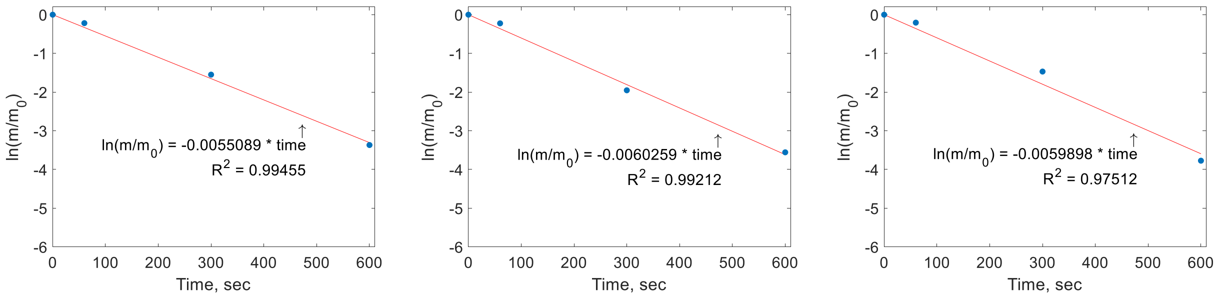

Figure A.21. First-order kinetic model for 7.5 kg/m^3 of sodium hydroxide and 200 ppm of sodium hypochlorite.

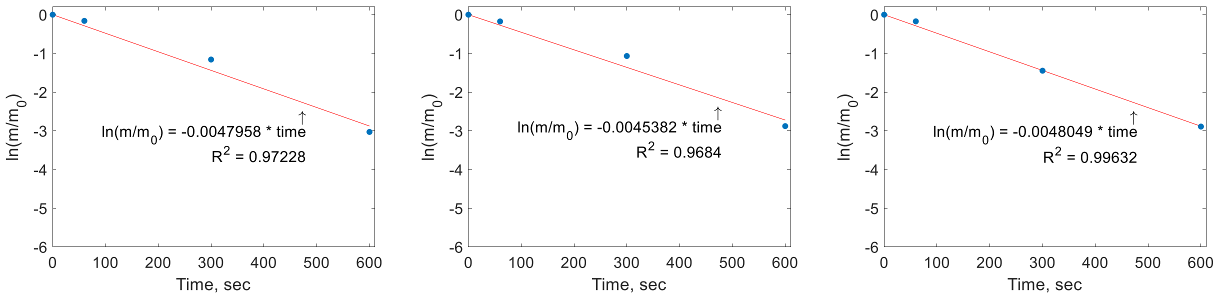

Figure A.22. First-order kinetic model for 15 kg/m^3 of sodium hydroxide and 0 ppm of sodium hypochlorite.

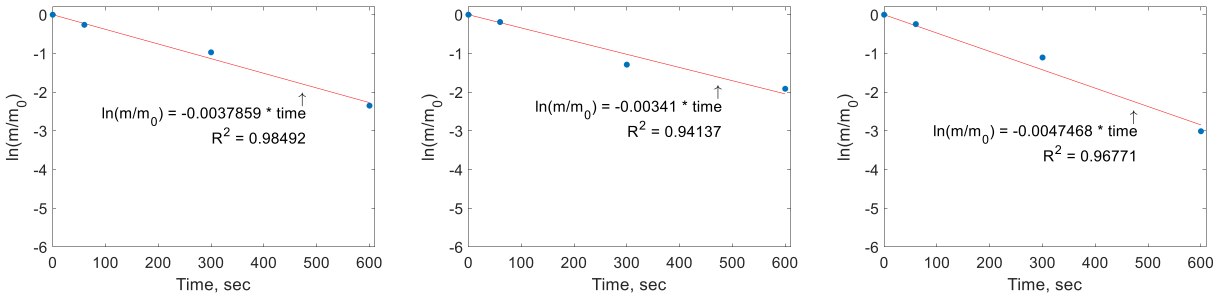

Figure A.23. First-order kinetic model for 15 kg/m^3 of sodium hydroxide and 50 ppm of sodium hypochlorite.

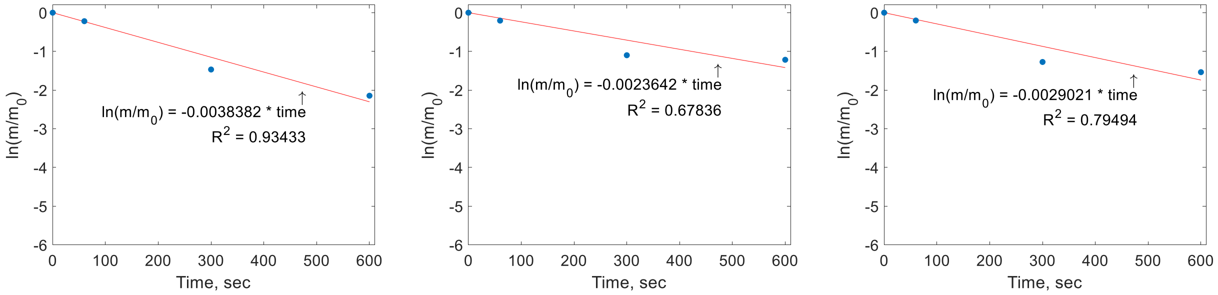

Figure A.24. First-order kinetic model for 15 kg/m^3 of sodium hydroxide and 100 ppm of sodium hypochlorite.

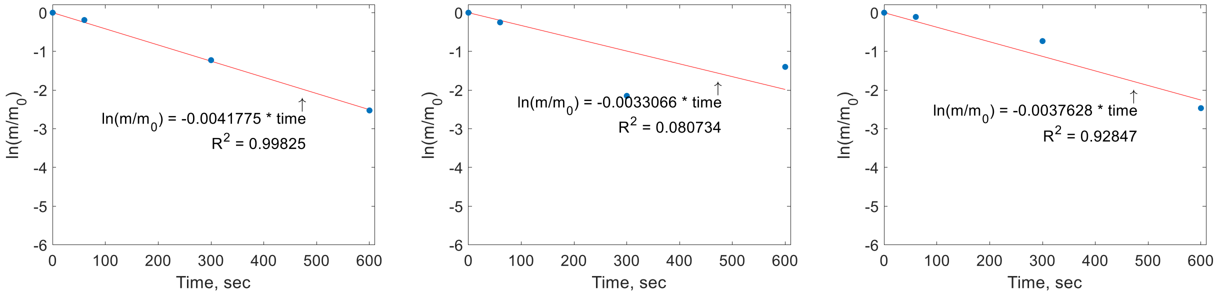

Figure A.25. First-order kinetic model for 15 kg/m^3 of sodium hydroxide and 150 ppm of sodium hypochlorite.

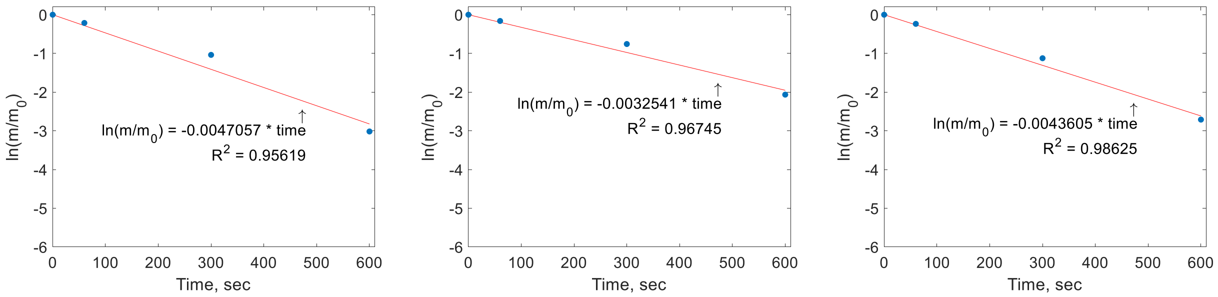

Figure A.26. First-order kinetic model for 15 kg/m^3 of sodium hydroxide and 200 ppm of sodium hypochlorite.

Table A.9. First-order kinetic model results

Caustic Conc., kg/m^3	Chlorine Conc., ppm	k	R^2
0	0	0.00138	0.85
0	0	0.00125	0.92
0	0	0.00123	0.77
0	50	0.00118	0.71
0	50	0.00147	0.67
0	50	0.00568	0.84
0	100	0.00135	0.86
0	100	0.00220	0.45
0	100	0.00127	0.31
0	150	0.00139	0.93
0	150	0.00130	0.25
0	150	0.00191	0.56
0	200	0.00123	0.30
0	200	0.00159	0.88
0	200	0.00237	0.99
0.5	0	0.00211	0.95
0.5	0	0.00251	0.98
0.5	0	0.00287	0.99
0.5	50	0.00199	0.97
0.5	50	0.00228	0.98
0.5	50	0.00220	0.98
0.5	100	0.00247	1.00

0.5	100	0.00213	0.68
0.5	100	0.00544	0.85
0.5	150	0.00235	0.98
0.5	150	0.00213	0.92
0.5	150	0.00258	0.96
0.5	200	0.00278	0.99
0.5	200	0.00222	0.96
0.5	200	0.00202	0.96
5	0	0.00491	0.97
5	0	0.00475	0.99
5	0	0.00424	0.98
5	50	0.00676	0.99
5	50	0.00899	0.91
5	50	0.00571	0.97
5	100	0.00458	0.97
5	100	0.00611	1.00
5	100	0.00699	0.92
5	150	0.00674	0.99
5	150	0.00801	0.92
5	150	0.00851	0.89
5	200	0.00603	0.96
5	200	0.00696	0.95
5	200	0.00571	0.99
7.5	0	0.00498	0.98
7.5	0	0.00479	0.98
7.5	0	0.00523	0.94
7.5	50	0.00662	0.98
7.5	50	0.00536	0.99
7.5	50	0.00628	0.96
7.5	100	0.00797	0.97
7.5	100	0.00571	0.99
7.5	100	0.00608	0.97
7.5	150	0.00601	0.95
7.5	150	0.00726	0.93
7.5	150	0.00712	0.95
7.5	200	0.00551	0.99
7.5	200	0.00603	0.99
7.5	200	0.00599	0.98
15	0	0.00480	0.97
15	0	0.00454	0.97
15	0	0.00480	1.00

15	50	0.00379	0.98
15	50	0.00341	0.94
15	50	0.00475	0.97
15	100	0.00384	0.93
15	100	0.00236	0.68
15	100	0.00290	0.79
15	150	0.00418	1.00
15	150	0.00331	0.08
15	150	0.00376	0.93
15	200	0.00471	0.96
15	200	0.00325	0.97
15	200	0.00436	0.99