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The Effect of Chlorine on the Reduction of Coliform and Total Suspended Solids (TSS) in Domestic Wastewater at Port X in Batam City

Pengaruh Kaporit Terhadap Penurunan Angka *Coliform* dan *Total Suspended Solid* (TSS) pada Air Limbah Domestik di Pelabuhan X Kota Batam

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ABSTRACT

Daily operational activities at Port X produce domestic wastewater with total coliform and TSS parameters that exceed the required quality standards. Total coliform and TSS contaminate water bodies and cause gastrointestinal diseases in humans. This study aims to determine the optimal dose of calcium hypochlorite and aeration duration to reduce Total Coliform and Total Suspended Solids (TSS) in domestic wastewater at Port X, Batam. Using a True Experimental design through a Pretest-Posttest Control Group approach (n=3 replicates), wastewater samples were treated with varying doses of chlorine (1.0, 1.5, 2.0 g/L) and aeration periods (2 and 4 hours). The data were analyzed using the Paired t-test and Wilcoxon Signed-Rank test ($\alpha < 0.05$). The results showed that the combination of 2 g/L of chlorine and 4 hours of aeration produced the highest removal efficiency, with a reduction of 82.71% in Total Coliform and 85.16% in TSS. This study confirms that optimizing chlorination-aeration parameters significantly improves effluent quality to meet regulatory standards, although monitoring chlorine residues remains crucial.
Keywords: Chlorine, domestic wastewater, agitation, aeration

ABSTRAK

Kegiatan operasional harian di Pelabuhan X menghasilkan limbah cair domestik dengan parameter total koliform dan TSS yang melampaui baku mutu yang dipersyaratkan. Total koliform dan TSS mencemari badan air serta menyebabkan penyakit gastrointestinal pada manusia. Penelitian ini bertujuan untuk menentukan dosis optimal kalsium hipoklorit dan durasi aerasi untuk menurunkan Total Coliform dan Total Suspended Solids (TSS) pada air limbah domestik di Pelabuhan X, Batam. Dengan menggunakan desain True Experimental melalui pendekatan Pretest-Posttest Control Group (n=3 ulangan), sampel air limbah diberi perlakuan dengan variasi dosis klorin (1,0; 1,5; 2,0 g/L) dan periode aerasi (2 dan 4 jam). Data dianalisis menggunakan uji Paired t-test dan Wilcoxon Signed-Rank test ($\alpha < 0,05$). Hasil penelitian menunjukkan bahwa kombinasi 2 g/L klorin dan aerasi selama 4 jam menghasilkan efisiensi penyisihan tertinggi, dengan penurunan Total Koliform sebesar 82,71% dan TSS sebesar 85,16%. Studi ini mengonfirmasi bahwa optimalisasi parameter klorinasi-aerasi meningkatkan kualitas efluen secara signifikan hingga memenuhi standar regulasi, meskipun pemantauan terhadap residu klorin tetap merupakan hal yang krusial.
Kata Kunci: Kaporit, limbah domestik, pengadukan, aerasi

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INTRODUCTION

Batam is one of the cities in the Riau Islands Province that has several ports as entry points and connections between domestic and international regions. The economic, social, and cultural development of the community is enhanced by the existence of ports. Ports also contribute indirectly to the advancement of education, international relations, and politics, and are often used as a measure of a region's development.[1]

Secondary data obtained from the Batam Class I Port Health Office shows that the total coliform and Total Suspended Solids (TSS) parameters exceeded the quality standards in the inspection of domestic waste samples from Port X, with the following results: total coliform parameter ≥ 16000 MPN/100 mL and TSS parameter 71 mg/L.[2] In an initial survey on March 1, 2024, physical observations were conducted at the final discharge outlet of domestic wastewater at Port X, the results of which showed that the wastewater was cloudy and had a foul odor.

TSS causes turbidity that limits light penetration for photosynthesis and visibility in water.[3,4] TSS usually consists of mud, clay, metal oxides, sulfides, algae, bacteria, and fungi. Total coliform concentrations higher than wastewater quality standards indicate the presence of infectious pathogens that spread disease through water.[5] High TSS levels can trigger an increase in coliform bacteria, as these bacteria can live on the elements that make up TSS. Therefore, effective wastewater treatment is necessary to prevent impacts on humans, such as diarrhea and other gastrointestinal diseases.

Domestic wastewater treatment must be carried out by port managers, considering that there are provisions on the implementation of healthy ports as stipulated in Minister of Health Regulation No. 44 of 2014 concerning the Implementation of Healthy Ports and Airports. Domestic waste is considered a risk factor that must be eliminated by implementing proper treatment.

Several treatment principles commonly used to reduce coliform and TSS contamination include filtration, aeration, adsorption, coagulation-flocculation, biofilm, phytoremediation, and disinfection. The application of all treatment stages will provide the best results, but there are obstacles such as the cost and availability of land to build the installation, so a concise but specific treatment plan based on the characteristics of the problems encountered is urgently needed.

Disinfection is one of the treatment stages for domestic wastewater that aims to eliminate pathogenic bacteria and oxidize suspended substances. The principles of disinfection can use ozonation, heating, and chlorination. Chlorination is usually carried out by adding chlorine because this material is economical, easy to store, and easy to apply.[4] In addition, chlorine in chlorine, especially HOCl, is generally effective in eliminating pathogens and indicator bacteria. Hypochlorite ions OCl- are also formed, which are capable of reducing organic and inorganic substances in waste.[4]

Khamimatus Salamatur Rohmah conducted a previous study showing that calcium hypochlorite dosage reduces total coliforms in wastewater at PKU Muhammadiyah Hospital in Surakarta. With

a reduction percentage of 99.834%, a dose of 1.5 g/L was the most effective in reducing all coliforms.[7] In addition, previous research by Tamzil Aziz et al. showed a reduction in TSS in the Lambidaro River water with the addition of chlorine as an oxidizer. Initially, the TSS concentration was 37.8 mg/L, but with the addition of 40 ppm chlorine, the concentration decreased by 24.33% to 28.6 mg/L.[8] Although the effectiveness of chlorination has been extensively studied in hospital wastewater [9] and rivers [10], specific studies on the optimization of chlorine dosage in domestic port wastewater are still limited. Port wastewater has unique characteristics with high fluctuations in organic load due to unpredictable passenger activity. This study fills this knowledge gap (gap analysis) by examining the synergy between mechanical aeration and chlorination to address the high chlorine demand in wastewater with varying salinity and turbidity, and evaluating its effectiveness against the strict standards of PermenLHK No. 68 of 2016.

MATERIALS AND METHODS

This study was a true experiment with a pretest-posttest control group design. The pretest group was not given any treatment, while the posttest group was given treatment. Domestic wastewater samples were taken using integrated sampling at the final discharge outlet of Port X, with a total volume of 47 liters. This volume was homogenized and distributed into 1-liter glass reactors. The study was conducted with 3 independent repetitions (triplicate, n=3) for each treatment combination (Dose x Time) to ensure statistical validity and minimize experimental error. The total number of experimental units consisted of a negative control group (without treatment) and a group with varying treatments. To avoid systematic bias, the allocation of sample units to the treatment groups was carried out using a completely randomized design. Each experimental unit was given a random code and placed at an aerator position that was rotated periodically to ensure uniform oxygen distribution between units.

The chlorine used was technical calcium hypochlorite (Ca(OCl)2) with an active chlorine content of 60%. The dose range (1.0; 1.5; 2.0 g/L) was selected based on the results of a preliminary test (range finding test) which showed that doses below 1 g/L did not produce measurable free chlorine residues (breakpoint chlorination was not achieved) due to the high ammonia content in domestic port waste. The equipment used was an automatic mixer and an automatic aerator. Water quality parameters were measured according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2012). Total coliforms were calculated using the 5-tube Most Probable Number (MPN) method (APHA 9221), while TSS was measured using the gravimetric method (SNI 06-6989.3-2004). Supporting parameters such as pH and temperature were measured in situ using a calibrated digital pH meter.

Statistical analysis began with the Shapiro-Wilk Normality Test, which was chosen because the number of samples per group was small ($n < 50$). Normally distributed data ($p > 0.05$) were analyzed using the Paired Sample t-test, while non-normally distributed data were analyzed using the

Wilcoxon Signed-Rank Test. All analyses were performed at a 95% confidence level (α = 0.05). Data were presented in tables and reinforced with descriptive statistics. The percentage decrease was calculated using the formula ((initial amount-final amount)/initial amount) x 100%).[11]

RESULTS

The TSS and coliform counts of domestic wastewater from Port X in Batam City did not meet the quality standards required in Ministerial Regulation LHK Number 68 of 2018. The TSS level test results showed 137 mg/L, while the coliform count test results showed >16,000 MPN/100 mL. These initial characteristics will be used as control data without treatment and as a comparison for each treatment variable. The TSS level test results and statistical analysis of the TSS level reduction data are presented in the following table.

Table 1. TSS Test Results on Samples

Independent Variables	Drop Difference (mg/L)	Percentage Decrease (%)	Statistical Test Results	
			a	*p-value*
Dosage Variation (gr/L)				
1	20,3	14,84		
1,5	38,7	28,22	,657	,049
2	48,3	**35,28**		
Dosage Variations and Stirring				
1 gr/L + 10 Minutes	36,3	26,52		
1 gr/L + 20 Minutes	52,7	38,44		
1.5 gr/L + 10 Minutes	40,0	29,20	,212	,003
1.5 gr/L + 20 Minutes	55,7	40,63		
2 gr/L + 10 Minutes	93,3	68,13		
2 gr/L + 20 Minutes	106,3	**77,62**		
Dosage Variation and Aeration				
1 gr/L + 2 jams	49,0	35,77		
1 gr/L + 4 jams	52,0	37,96		
1.5 gr/L + 2 jams	51,0	37,23	,007	,028
1.5 gr/L + 4 jams	52,7	38,44		
2 gr/L + 2 jam	108,3	79,08		
2 gr/L + 4 jam	116,7	**85,16**		

Source: Primary data, 2024

Based on the data in Table 1, it is known that there was a decrease in TSS levels after treatment with varying doses, stirring, and aeration. The decrease in TSS levels with the addition of chlorine alone reduced TSS the most at a dose of 2 g/L, with a percentage decrease of 35.28%. Dose variation and agitation were able to reduce TSS levels more effectively than without agitation. Agitation

variations of 10 minutes and 20 minutes reduced TSS most effectively at a dose of 2 g/L, with reduction percentages of 68.13% and 77.62%, respectively. The best reduction in TSS levels occurred at a dose of 2 g/L and aeration for 4 hours, with a reduction percentage of 85.16%. A normality test was performed on the TSS reduction data, and the results showed that the treatment data for dose and agitation variations were normally distributed with α >0.05, while the aeration treatment data were not normally distributed because α <0.05.

Table 2. Coliform Number Test Results on Samples

Independent Variables	Drop Difference (mg/L)	Percentage Decrease (%)	Statistical Test Results	
			a	*p-value*
Dosage Variation (gr/L)				
1	7833,3	48,96%		
1,5	9933,3	62,08%	,934	,016
2	12300,0	76,88%		
Dosage Variations and Stirring				
1 gr/L + 10 Minutes	8066,7	50,42%		
1 gr/L + 20 Minutes	8366,7	52,29%		
1.5 gr/L + 10 Minutes	10833,3	67,71%	,232	,000
1.5 gr/L + 20 Minutes	11133,3	69,58%		
2 gr/L + 10 Minutes	12333,3	77,08%		
2 gr/L + 20 Minutes	12533,3	78,33%		
Dosage Variation and Aeration				
1 gr/L + 2 jams	9900,0	61,88%		
1 gr/L + 4 jams	10066,7	62,92%		
1.5 gr/L + 2 jams	11366,7	71,04%	,318	,000
1.5 gr/L + 4 jams	11433,3	71,46%		
2 gr/L + 2 jam	13033,3	81,46%		
2 gr/L + 4 jam	13233,3	**82,71%**		

Source: Primary data, 2024

A paired t-test was conducted to examine the effect of dose variation and agitation on the reduction in TSS levels. Meanwhile, the aeration treatment data was tested using non-parametric statistics, namely the Wilcoxon test. The paired t-test and Wilcoxon test showed that there was an effect of the variables of dose variation, agitation,

and aeration on the reduction in TSS levels with p-values < 0.05. Based on these test results, it was concluded that there was an effect of the independent variables on the dependent variable (reduction in TSS levels), so Ha was accepted and H0 was rejected.

Based on the data in Table 2, it is known that there was a decrease in coliform counts after treatment with varying doses, agitation, and aeration. The addition of chlorine resulted in the greatest decrease at a dose of 2 g/L with a percentage decrease of 76.88%. The addition of agitation increased the percentage decrease to 78.33% at a dose of 2 g/L and agitation for 20 minutes. The best reduction occurred at a dose of 2 g/L and aeration for 4 hours, with a reduction percentage of 82.71%.

A normality test was performed on the coliform count reduction data, and the results showed that the data on the treatment of varying doses, agitation, and aeration were normally distributed with $\alpha > 0.05$, so a parametric test could be performed to test the effect of the independent variables on the dependent variables.

A paired t-test was performed to test the effect of variations in dosage, stirring, and aeration on the reduction in coliform counts. The paired t-test showed that there was an effect of the variables of dosage variation, stirring, and aeration on the reduction in coliform counts, as indicated by a p-value <0.05. It can be concluded that the independent variables affect the dependent variable, so Ha is accepted and H0 is rejected.

DISCUSSION

Variations in chlorine dosage have different abilities to remove TSS levels in samples. The superior effectiveness of the combination of a 2.0 g/L dosage and 4 hours of aeration (85.16% reduction in TSS) can be explained through the synergistic mechanism of chemical and physical oxidation. Chemically, a high chlorine dose is required to exceed the breakpoint chlorination point in port wastewater rich in ammonia. Chlorine reacts to oxidize ammonia into nitrogen gas before free chlorine residues are available for bacterial inactivation. Physically, aeration for 4 hours facilitates two processes: (1) oxygen supply that accelerates the aerobic degradation of suspended organic matter; and (2) a mechanical coagulation effect in which air bubbles help colloidal particles collide and form flocs that settle more easily, thereby significantly reducing TSS.[6]

Removal of organic and inorganic pollutants in the early stages of treatment will help chlorine effectively reduce TSS components. Therefore, the disinfection stage should be carried out after the treatment of organic and inorganic pollutants. There are several types of treatment techniques to reduce organic and inorganic pollutants in domestic wastewater, one of which is commonly done is the use of a bacterial reactor or what is often known as a biofilm reactor.[11]

Compared to Aminullah's study, which required an extreme dose of 10 g/L for hospital wastewater, this study achieved equivalent efficiency (>80%) with only 2.0 g/L. This indicates that pre-treatment in the form of mechanical aeration is very effective in reducing the initial organic load, thereby significantly reducing

chlorine consumption. However, when compared to the study by Aziz et al. which achieved a 99% reduction in river water, the 82% efficiency in this study indicates that port wastewater has more resistant shielding particles, possibly in the form of oil or grease from ship activities that protect bacteria from direct contact with chlorine.[12]

Ammonia itself is a very common organic pollutant found in domestic wastewater, and its presence affects the dose of chlorine used. The higher the ammonia content in domestic wastewater, the more chlorine is needed to decompose it. This will affect the ability of ammonia to reduce TSS in the sample. It is important to note that the use of high doses of chlorine (2 g/L) carries secondary environmental risks. The hydrolysis of calcium hypochlorite releases hydroxide ions (OH-) which have the potential to raise the pH of the effluent above the threshold of 9.0, which can kill the biota in the receiving water body. In addition, the reaction between free chlorine and humic organic matter in wastewater risks forming Disinfection By-Products (DBPs) such as Trihalomethanes (THMs), which are carcinogenic. Therefore, even if the microbiological target is achieved, it is recommended that the treated effluent undergo pH neutralization and dechlorination (e.g., with sodium thiosulfate) before being discharged into water bodies.

Aeration is a domestic waste treatment process that aims to increase the oxygen content in samples to aid in the degradation of contaminants with the help of oxygen. The aeration process creates air bubbles that rise to the surface, causing the sample to circulate. This circulation also aids in the dissolution of chlorine due to the simultaneous movement of the sample. The air bubbles produced by the oxygen aerator cause the surface of the sample to come into contact with free oxygen in the air, so that oxygen in the free air also enters the sample.[13]

The higher the amount of oxygen, the greater the oxidation activity of organic substances in the sample. Oxygen plays an important role in the oxidation process of organic substances into simpler compounds. In principle, this process is called the aerobic process, where organic compounds are oxidized into CO2, H2O, and NH3.[14] The reduction of organic substances through the aeration process can improve the performance of chlorine in reducing TSS compounds in the sample. This study proves that aeration for 4 hours can reduce TSS levels better than shorter aeration periods of 2 hours at the same chlorine dose.

The ability of chlorine to inactivate pathogenic bacteria in samples is influenced by the dose administered. Previous studies have shown that chlorine is a disinfectant that is often used to reduce microbiological contamination indicators, given its ability to inactivate and destroy pathogenic bacteria in wastewater. Chlorine can destroy indicator bacteria by damaging the permeability of cells, nucleic acids, and enzymes of pathogenic bacteria, as well as inhibiting cell metabolism. Free chlorine produced when chlorine reacts with wastewater causes leakage of proteins, RNA, and DNA in bacteria. Chlorine also damages permeability, which means it causes damage to bacterial spores.[15]

The dose affects the ability of chlorine as a disinfectant against indicator bacteria, which is influenced by the amount of hypochlorous acid formed when chlorine reacts with water. Hypochlorous acid acts as a cell membrane destroyer in bacteria and stops metabolism, causing the bacteria to die or be destroyed.[16]

Aeration in domestic wastewater helps create aerobic conditions, so that organic chains can be broken down into other forms, namely CO2 and H2O, through the following equation: [17,18]

$C6H12O6 + 6\ O2 \rightarrow 6\ CO2 + 6\ H2O$

Longer aeration duration breaks down organic and inorganic contaminants more effectively, allowing chlorine to work optimally for coliform removal.[4]

Coliform bacteria are divided into two groups: fecal and non-fecal. Fecal coliforms are indicator bacteria of contamination that cause gastrointestinal diseases in humans. Meanwhile, non-fecal coliform bacteria originate from the decomposition of plant debris and animal carcasses.[19]

Coliform bacteria thrive on organic substances found in domestic waste. The aeration treatment process aims to break down organic substances, thereby degrading the living elements of coliform bacteria.[16]

CONCLUSION AND SUGGESTIONS

Variations in chlorine dosage, agitation, and aeration in domestic wastewater from Port X in Batam City can reduce TSS levels and coliform counts, with the highest reduction percentage occurring at a chlorine dosage of 2 g/L and aeration for 4 hours, resulting in an 85.16% reduction in TSS levels and an 82.71% reduction in coliform counts. Variations in chlorine dose and aeration duration significantly affect the reduction in TSS and coliform ($p < 0.05$\$). The optimal configuration was achieved at a dose of 2.0 g/L with 4 hours of aeration, producing effluent that met the quality standards of PermenLHK P.68/2016.20. It is recommended that Port X Management install an aeration tank with a minimum detention time of 4 hours before the chlorination tank. Routine monitoring of free chlorine residual (target 0.2–0.5 mg/L) is mandatory to prevent overdosing, which triggers the formation of toxic compounds. Given the limitations of this study, which did not measure pH in real-time or THM residue concentrations, further research is recommended to integrate automatic pH control and gas chromatography analysis to detect disinfection byproducts for long-term ecological safety.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

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