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Original Research Article

Physical and Chemical Treatability Assessment for Food Industry Wastewater in Wastewater Treatment Plant Design

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Abstract
Food industry wastewater has characteristics that contain high organic matter and suspended solids. Most of the methods used are physical and chemical treatment because these methods have high efficiency and effectivity. In designing a new wastewater treatment plant, the treatability assessment is essential to any consideration or reference in planning the treatment process to be implemented. This research aims to obtain treatability assessment results that will be used as consideration in planning treatment units in WWTP according to the characteristics of wastewater tested. The removal results of the sedimentation test with Imhoff Cone were able to remove 51.2% COD, 64.04% BOD, and 95.21% TSS with the optimum settling time of 40 minutes. The samples test continued to the rapid-slow mixing test using the jar test, resulting that by adding coagulant at the optimum dose of PAC 120 mg/L, it was capable to remove 68.21% of COD, 73.22% of BOD, and up to 98.07% of TSS at the end of the process. Based on the assessment results, the physical and chemical treatment can remove suspended solids pollutant parameters with high efficiency so it will be considered to be used in planning Wastewater Treatment Plants for this food industry.

Keywords: Imhoff cone; jar test; rapid mixing; sedimentation; slow mixing; TSS

1. Introduction

Industrial wastewater is a complex and diverse form of wastewater that originates from a multitude of sources, each exhibiting distinct characteristics. Among the various industries, the food industry stands out due to its significant contribution of wastewater, which contains a substantial concentration of organic matter. These organic substances can exist in dissolved form or as suspended solids, making the treatment of food industry wastewater particularly challenging. To effectively address the unique composition of food industry wastewater, physical and chemical treatment methods have emerged as the primary approaches employed. These methods offer notable advantages, such as high treatment efficiency and a smaller processing footprint. By leveraging physical and chemical treatment techniques, industries can efficiently remove pollutants, mitigate environmental impacts, and comply with regulatory standards without requiring extensive space for treatment facilities. Physical treatment methods typically involve the separation of suspended solids through processes like sedimentation, filtration, or flotation. These techniques enable the removal of solid particles, fats, oils, and greases, significantly reducing the organic load in the wastewater. Chemical treatment, on the other hand, employs chemical agents or processes to enhance the removal of contaminants. Coagulation, flocculation, and advanced oxidation processes are examples of chemical treatment methods commonly employed in the food industry. Physical and chemical treatment methods not only facilitate the removal of organic matter but also address other pollutants such as nutrients, heavy metals, and toxic compounds. These methods are known for their versatility and adaptability to various wastewater streams within the food industry, enabling the treatment of diverse effluents generated by food processing, beverage production, dairy operations, and more. The application of physical and chemical treatment methods in the food industry's wastewater management underscores the industry's commitment to environmental sustainability and responsible resource utilization. By effectively treating industrial wastewater, the food industry can minimize its ecological footprint, safeguard water resources, and contribute to the overall preservation of our environment.

The combination of chemical and physical treatability tests is done by considering the wastewater's characteristics and the treatment purpose. Treatability assessments typically involve only one or a few samples, so the sample must be representative of the wastewater. Therefore, the samples are typically composite samples collected over a normal operations cycle and ideally should contain the expected full-scale, maximum concentrations of all components. Otherwise, the treatability tests could miss the bad effects of loading rates (Water Environment Federation, 2008).

The suspended solids can be discharged with physical process such as sedimentation because they will ultimately settle. The sedimentation test can be carried out using a settling tank simulation tool which is an Imhoff cone. The sedimentation test using the Imhoff cone aims to see the settling efficiency of suspended solids as a basis for determining and considering the need for a physics treatment unit in the form of sedimentation at the initial stage of processing (Tchobanoglous et al., 2014). The sedimentation process in wastewater treatment involves allowing the wastewater to flow slowly through a large tank, providing sufficient time for suspended solids to settle. The settled solids form a sludge layer at the bottom of the tank, while the clarified water is collected and further treated. Sedimentation plays a crucial role in reducing the concentration of suspended solids, thus improving the overall quality of the treated wastewater.

Jar tests were carried out to determine the dosage of chemicals and the requirements used to obtain optimum results. Determination of the optimum dose is determined by looking at the lowest TSS value among the doses that have been tested with a jar test. Determination of the optimum dosage will be used in planning the WWTP to pay attention to the economic aspects of the WWTP so that the purchase of the coagulant used can be efficient and does not incur high costs (Zakaria et al., 2021).

Various types of coagulants are widely used in the food industry wastewater treatment, such as PAC (Poly Aluminum Chloride). PAC has a high degree of polymerization, which makes it good for low alkalinity waters that require fast decolorization and reaction times. PAC contains 10-12% Al_2O_3 and a base content of at least 50%. The chemical properties of PAC are effectively used as coagulants at pH 4 to 7. The coagulation power of PAC is greater than that of alum and can produce stable flocs even at low temperatures and is easy to process (Anugrah, 2013).

In designing the new wastewater treatment plant, consideration must be given not only to the physical facilities required to produce a high-quality effluent, but also to enable the minimizing of operating costs associated with labor, energy (both electrical and for heating), and byproduct stabilization and disposal/reuse. Further, as scientific research continues in defining wastewater components that may cause negative effects, greater levels of treatment will be needed, and, in some cases, will require the usage of new technologies (Tchobanoglous et al., 2014). Treatability assessment is essential to any consideration or reference in planning the processing units to be used. Therefore, this research aims to obtain treatability assessment results that will be used as consideration in planning treatment units in WWTP according to the characteristics of wastewater tested.

2. Methods

In this research, the wastewater used is from the snack food industry. Wastewater samples are taken directly to the industrial location using the Composite Sampling method, which takes samples of wastewater at different times and in the same place. This sampling method was used because it will represent the fluctuations of the flow of wastewater resulting from the snack production process. The tools used in water sampling are plastic buckets and long sticks. The sample container used when taking samples uses a bottle made from HDPE (High Density Polyethylene) because it is stable so it can prevent chemical reactions between the sample and the container. Then the sample is stored in that 1 liter bottle for a while. Then to mix the wastewater from the composite sampling results, it's mixed in 10 liter HDPE drum with the composition of each sample calculated.

The samples are taken during factory operating hours at the equalization tank inlet from 11.00 to 20.00 with sampling intervals and discharge measurements every 1 hour. Therefore, the need for a test sample is 10 liters with a total time of taking every 1 hour. To find out the required volume composition for each hour of collection, the multiplier factor can be calculated using the following formula (Benefield and Randall, 1980).

$$Portion\ of\ sample\ needed\ per\ unit\ of\ flow = \frac{total\ volume\ of\ sample\ desired}{[average\ flow\ rate] \times [number\ of\ samples\ to\ be\ mixed]} \quad ....(1)$$

Here is the data quantity of the wastewater obtains during composite sampling and the composition of the samples needed for each hour.

Table 1. Sample composition from composite sampling

No.	Time	Flow (m^3/jam)	GPM	Volume of sample for each hour (mL)	Volume of sample for each hour (L)
1	11,00	10.497	46.215	1090.152	1.0902
2	12,00	10.497	46.215	1090.152	1.0902
3	13,00	9.249	40.721	960.547	0.9605
4	14,00	1.503	46.243	1090.801	1.0908
5	15,00	9.249	40.721	960.547	0.9605
6	16,00	9.257	40.756	961.370	0.9614
7	17,00	9.257	40.756	961.370	0.9614
8	18,00	9.258	40.763	961.543	0.9615
9	19,00	9.260	40.769	961.672	0.9617
10	20,00	9.261	40.776	961.846	0.9618
Portion of sample needed per unit of flow				**23.588**	

The sedimentation test was executed by pouring 1 liter of mixed sample into the Imhoff cone. Then the samples were left undisturbed and observed for the velocity of settling. The observation time in this test was 45 minutes and the settling volume was recorded at 5 minutes intervals. The results of observations can be seen in the following figure.

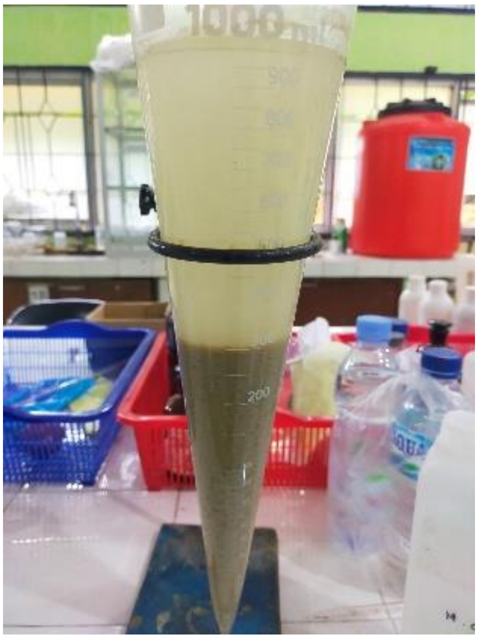

Figure 1. Imhoff cone test

The supernatants from the sedimentation test continued to be tested to rapid-slow mixing test by jar test. Rapid-slow mixing test by jar test using a test method based on national standards for rapid-slow mixing test method utilizing the jar test stipulated in SNI 19-6449-2000 including general procedures for processing to reduce dissolved, colloidal and non-precipitated materials in water using chemicals in the rapid-slow mixing process, followed by gravitational settling.

The coagulant used in this test is $Al2(SO4)3$, $FeCl_3$, and Poly Aluminum Chloride (PAC). Another consideration in using PAC as a coagulant is that because of the chemical nature of PAC, it is effectively used as a coagulant at pH 4 to 7. This is suitable for the characteristics of the wastewater tested which has a pH of 4.7. In the initial conditions, pH conditioning will be carried out using the pH adjuster NaOH and H2SO4 until the sample atmosphere becomes neutral at pH 7.5 – 8 so that the coagulant can work optimally.

The sample to be tested was then added with a coagulant with several different doses in each beaker glass. Before running the jar test, the initial pH of the sample has to be calculated using a pH meter or universal indicator. The dose of added coagulant is not added quantitatively but by estimation, so it has to be done using the jar test method (Zakariya et al., 2021). In this research, the estimation of coagulant dosage added starts from 60 mg/L, 70 mg/L, 80 mg/L, 90 mg/L, 100 mg/L, 110 mg/L, 120 mg/L, 130 mg. /L, 140 mg/L, 150 mg/L, and 160 mg/L. To determine the amount of PAC 1% solution added to the sample can be measured by the equation shown below.

$$Volume\ of\ coagulant\ solution\ desire = \frac{Dosage\ \times Vsample}{[Coagulant]} \quad \text{.......................................(2)}$$

Dosage = Coagulant dosage desired (mg/L)
V_{sample} = Volume of sample tested (mL)
[Coagulant] = Coagulant concentration (PAC 1%) (mg/L)

The test was continued using the jar test apparatus with rapid mixing (coagulation) at 120 rpm for 1 minute and continued with slow mixing (flocculation) at 60 rpm for 10 minutes and 30 rpm for 10 minutes. The rapid mixing process is carried out with fast stirring so that good turbulence occurs and the chemicals can capture colloidal particles (Risdianto, 2007). Rapid mixing is only done briefly ± 30-60 seconds. Furthermore, the mixing is continued in the second stage, namely the flocculation process in which unstable particles coalesce to form larger flocs and can be separated more quickly. Flocculation is done by slow mixing with a time of 5-30 minutes. The sample was then left for 30 – 60 minutes until the precipitate and supernatant separated. To find out the optimal dose, pH and TSS testing were carried out for each dose.

Figure 2. Jar test with PAC coagulant

3. Result and Discussion

3.1 Wastewater Characteristic

To determine the quality of wastewater produced by an industry, the characteristics of wastewater that have been taken compositely at the equalization inlet are tested at the Environmental Engineering Laboratory. The wastewater characteristics results are compared with the quality standards that are used as a reference, based on the regulation of Peraturan Menteri Lingkungan Hidup Republik Indonesia Nomor 5 Tahun 2014 (Appendix XLVII). A summary of the test results for all parameters can be seen in the following table.

Table 2. Characteristics of wafer industry wastewater

No.	Parameters	Result	Reffered Standar		Unit	Method
			Category I	Category II		
1	Temperature	28.6	-	-	^{0}C	
2	pH	4.7	-	-	-	SNI 6989.11:2019
3	Color	2,377.667			mg/L	SNI 6989.80:2011
4	TSS	8695	200	400	mg/L	SNI 6989.3:2019
5	TDS	1980	2000	4000	mg/L	SNI 6989.27:2019
6	BOD5	7,026.316	50	150	mg/L	SNI 6989.72:2009
7	COD	10,820	100	300	mg/L	SNI 6989.2:2019
8	Nitrat	15.283	20	30	mg/L	SNI 6989.79:2011
9	Nitrit	0.0442	1	3	mg/L	SNI 06-6989.9-2004
10	Amonia	0.7194	5	10	mg/L	SNI 06-6989.30-2005
12	Total N	26.6505	30	60	mg/L	Base Destruction Indofenol
13	Oil and Grease	9.274	10	20	mg/L	SNI 6989.10-2011
14	Fosfat	1.862	-	-	mg/L	SNI 6989.31-2005

From all the parameters tested, it was shown that the pollutant parameters that did not meet the quality standards were COD, BOD, and TSS. Parameters that will be tested for elimination check in the physical and chemical treatability tests are parameters that do not meet these quality standards.

3.2 Sedimentation Test

In this sedimentation test, the result was that the precipitate formed at 30 minutes was at the 348 mL position of the Imhoff cone. Then the sample stopped precipitating at 40 minutes with the amount of sediment formed was 300 ml. Furthermore, the supernatant from the sample will go through a pollutant parameter test that does not meet quality standards, which are COD, BOD, and TSS to see the removal efficiency of this sedimentation process.

Table 3. Imhoff cone removal result

Parameters	Initial Result (mg/L)	Final Result (mg/L)	Removal Efficiency
COD	10820	5280	51.20%
BOD	7026.316	2526.316	64.04%
TSS	8695	416.667	95.21%

From the data above, the results show that the primary sedimentation process can remove 51.2% of COD, 64.04% of BOD, and 95.21% of TSS with an optimum time of 40 minutes. The parameters removed in this process are particulates which can be removed without any addition of chemical processes such as coagulants or biological such as decomposition by microorganisms. These results indicate that the initial physical processing, i.e., sedimentation, is efficient in removing pollutant parameters. So that in wastewater treatment plant planning, pre-treatment sedimentation units can be used to design the treatment process.

3.3 Jar Test

This research uses several types of coagulants. The result shown below is the most optimum coagulant among the others, which is Poly Aluminum Chloride (PAC).

Table 4. Jar test result

Dosage (mg/L)	Initial pH (after pH adjuster added)	Final pH	Initial TSS (mg/L)	Final TSS (mg/L)	TSS Removal Efficiency
60	8.4	8.32	416.667	381.67	8.40%
70	8.4	8.27	416.667	329.33	20.96%
80	8.4	8.24	416.667	316	24.16%
90	8.4	8.19	416.667	294.73	29.26%
100	8.4	8.14	416.667	279.67	32.88%
110	8.4	8.1	416.667	244	41.44%
120	8.4	7.75	416.667	168	59.68%
130	8.4	7.6	416.667	176	57.76%
140	8.4	7.21	416.667	204	51.04%
150	8.4	7.04	416.667	220	47.20%
160	8.4	6.3	416.667	256	38.56%

The data obtained from the jar test results indicate that the optimum dose of the PAC (Polyaluminum Chloride) coagulant for treating the wastewater is 120 mg/L. At this dosage, the coagulant demonstrated the highest removal efficiency for Total Suspended Solids (TSS), achieving a removal efficiency of 59.68%. This means that the PAC coagulant effectively aids in the aggregation and precipitation of suspended solids, facilitating their removal from the wastewater. Additionally, it is observed that the pH of the wastewater has decreased after the addition of the PAC coagulant. This decrease in pH indicates that the wastewater has become more acidic compared to its initial pH. This aligns with the well-known phenomenon that the use of coagulants, such as PAC, can lead to the release of hydrogen ions (H+). When PAC is added to water, it hydrolyzes and forms aluminum hydroxide flocs. During this process, the coagulant reacts with water molecules and releases hydrogen ions, resulting in a decrease in pH. The released hydrogen ions contribute to the acidification of the treated wastewater. The change in pH is an important parameter to monitor in the coagulation process as it can influence various factors such as the stability of colloidal particles, the effectiveness of coagulation, and the subsequent treatment processes. In some cases, adjusting the pH to a specific range may be necessary to optimize coagulation efficiency and achieve the desired treatment objectives. It is worth noting that the decrease in pH caused by the addition of coagulants should be carefully managed to ensure it remains within the acceptable range for both the treatment process and the receiving environment. Acidic pH levels can have detrimental effects on aquatic life and may require subsequent pH adjustment or neutralization before the treated wastewater is discharged or further processed. In conclusion, the jar test results indicate that a PAC coagulant dosage of 120 mg/L offers the highest TSS removal efficiency for the wastewater being treated. The addition of PAC causes a decrease in pH due to the release of hydrogen ions during the coagulation process. Managing and monitoring the pH levels are essential considerations to maintain effective wastewater treatment and prevent any adverse impacts on the environment.

At coagulant doses of 130 mg/L to 160 mg/L, it can be seen that the turbidity and TSS of the samples have increased again. This can happen because the dose has exceeded the optimum dose so that the sample becomes saturated and the pH conditions are no longer optimal for the coagulant to work. The addition of coagulants is the addition of cations to neutralize the negative charge of colloidal particles in water resulting in Van der Waals forces, which causes colloidal particles to flocculate. With the addition of PAC with a dose above the optimum dose, the cations released are too much in excess than required by the negatively charged colloidal particles in water to form flocs. As a result, there will be excessive absorption of cations by colloidal particles in water so that the colloidal particles will be positively charged and there will be repulsive forces between the particles, resulting in floc deflocculation. Floc deflocculation will cause the solution to become increasingly turbid and the TSS value to increase (Budiman, 2008).

After testing, the optimum dosage results were obtained using PAC (Poly Aluminum Chloride) coagulant at a dose of 120 mg/L. Furthermore, samples with optimum doses were tested for pollutant parameters that did not meet quality standards for efficiency removal checking.

Table 5. Optimum dose of PAC coagulant efficiency removal

Parameters	**Initial Result (mg/L)**	**Final Result (mg/L)**	**Removal Efficiency**
COD	5280	3440	34.85%
BOD	2526.316	1881.68	25.52%
TSS	416.667	168	59.68%

Based on the data above, it can be seen that the addition of coagulants can remove 34.85% of COD, 25.52% of BOD, and up to 59.68% of TSS. Overall, the physical and chemical test combination in this treatability assessment resulting high removal efficiency at the end of its processes as shown in the table below.

Table 6. Physical and chemical treatability assessment result

Parameters	Initial Result (mg/L)	Final Result (mg/L)	Removal Efficiency
COD	10820	3440	68.21%
BOD	7026.316	1881.68	73.22%
TSS	8695	168	98.07%

This research proved that the addition of coagulants after the sedimentation process can remove 68.21% of COD, 73.22% of BOD, and up to 98.07% of TSS at the end of the processes. Coagulation methods are generally successful in reducing levels of organic matter (COD, BOD) by 40-70%. Even though the removal efficiency is high, the addition of coagulant has not been able to remove COD and BOD below the quality standard and only can fulfill the quality standard for TSS. Most of the wastewater treatment methods that have been carried out by food and beverage factories are chemical methods, namely coagulation-flocculation using chemicals because this method is considered to be faster and does not require too large a processing area to remove suspended solids. The mixing process will also affect energy-saving calculations so it is expected that the process can take place optimally with not high energy consumption. The use of a rapid-slow mixing (coagulation and flocculation) unit will be included in the WWTP planning.

4. Conclusions

Chemical and physical treatability assessment in the form of sedimentation tests with imhoff cone and jar tests using PAC coagulants in this test gave high removal results for pollutant parameters that did not meet the wastewater. The results of the removal in the sedimentation test with the Imhoff cone were that it was able to remove 51.2% COD, 64.04% BOD, and 95.21% TSS with an optimum time of 40 minutes. For the rapid-slow mixing test by the jar test, it was found that by adding coagulant at the optimum dose, which PAC at a dose of 120 mg/L, capable to remove 34.85% of COD, 25.52% of BOD, and up to 59.68% of TSS. Overall, the physical and chemical test combination in this treatability assessment resulting high removal efficiency at the end of its processes with a total removal efficiency presentation of 68.21% of COD, 73.22% of BOD, and up to 98.07% of TSS and its already fulfill the quality standard for TSS parameter. Based on the test results, the physical and chemical treatment units can remove suspended solids and pollutant parameters with high efficiency so that the use of physics and chemical units can be used in designing Wastewater Treatment Plants for the food industry.

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