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Treatment of Fish Processing Wastewater by Alum and PAM: A Comparative Study on Turbidity, COD, BOD, and Rheological Properties

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ABSTRACT

This research article compares the efficacy of using alum and poly aluminum chloride (PAM) for the treatment of fish processing wastewater. This study aims to determine the effectiveness of each treatment method in reducing turbidity, COD), BOD, and altering the rheological properties of the wastewater. Batch mode coagulation and flocculation experiments were conducted using lab scale jar test apparatus. The findings indicate that both alum and PAM can significantly reduce turbidity and COD. The highest turbidity removal efficiency of 93% was achieved with alum at a dose of 200 mg/L, while PAM achieved a maximum turbidity removal efficiency of 86% at a dose of 100 mg/L. Alum and PAM achieved the highest BOD5 and COD removal efficiencies at a dosage of 200 mg/L and pH 7.0. However, the removal efficiencies varied at different pH values and dosages. Alum and PAM have significant effect on the rheological properties of fish processing wastewater. The viscosity of settled residual sludge after chemical coagulation is more compared to untreated fish processing wastewater due to aggregation of suspended particles to form larger flocs. This would improve the settling properties of the coagulated sludge. The study concludes that both alum and PAM can be viable options for treating fish processing wastewater, with Alum showing a slight edge over PAM in certain aspects.

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INTRODUCTION

Fish processing units in Oman play a crucial role in the country's economy, as Oman has a rich coastline with abundant fishery resources. These processing units are involved in various activities such as fish handling, processing, packaging, and export.

Processing of fish for human consumption involves significant water consumption, on the average equal to 11 m^3/ton of fish processed (Lim et al., 2003), and it is known to contain high levels of turbidity, chemical oxygen demand (COD), and biological oxygen demand (BOD), which pose environmental challenges for proper treatment and disposal (Ray et al., 2010). The discharge of untreated or inadequately treated fish processing wastewater can result in water pollution, degradation of aquatic ecosystems, and harm to human health (Bureau of Fisheries and Aquatic Resources, 2016). Therefore, effective treatment methods are crucial to mitigate the environmental impact of fish processing wastewater.

Various physico-chemical, and biological techniques have been studied for their applicabili-

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ty to the treatment of fish processing wastewater (Takeshita et al., 2020). Among these are sedimentation, filtration, screening, coagulation and flocculation, advanced oxidation processes, activated sludge process and sequencing batch reactor (SBR), anaerobic digestion and Upflow anaerobic sludge blanket (UASB)(Youravong and Marthosa, 2017; Mannacharaju et al., 2019; Chowdhury et al., 2010)

Coagulation and flocculation are commonly used methods for treating wastewater, including fish processing wastewater. Alum (Al2(SO4)3) and polyacrylamide (PAM) are widely used chemicals due to their excellent coagulation and flocculation properties (Bhamidipati et al., 2021). Alum acts as a primary coagulant by neutralizing the charge of suspended particles and promoting their aggregation, while PAM, a synthetic polymer, enhances the flocculation process by bridging and binding the flocs together (Lee and Chang, 2022).

The coagulation process, promoted by using alum and PAM, is not a novel concept, and many researchers have investigated the coagulation of wastewater. Despite their widespread use, the effectiveness of alum and PAM in treating fish processing wastewater, as well as their impact on the rheological properties of the wastewater, have not been thoroughly studied. Therefore, the objective of this paper is to compare the efficiency of alum and PAM in removing turbidity, COD, and BOD from fish processing wastewater, and to investigate their effects on the rheological properties of the treated wastewater.

The findings of this study will contribute to the understanding of the effectiveness of alum and PAM as coagulants and flocculants for treating fish processing wastewater, and their impact on the rheological properties of the treated wastewater. The results may have important implications for the development of efficient and sustainable treatment methods for fish processing wastewater, which can help protect the environment and safeguard public health.

MATERIALS AND METHODS

Sample Collection

Fish processing wastewater samples were collected from Nizwa fish market in sterile plastic containers and transported to the laboratory for analysis within 24 hours to ensure the freshness of the samples.

Characterization of Fish Processing Wastewater

The collected wastewater samples were characterized for turbidity, COD, and BOD. Turbidity was measured using a turbidity meter (Model: TU-2016, Hach Company) according to the standard methods (Baird et al., 2017). COD and BOD were determined using the closed reflux colorimetric method and the standard dilution method, respectively (Baird et al., 2017).

Coagulation-Flocculation Experiments

Alum ($Al_2(SO_4)_3$) and polyacrylamide (PAM) were used as coagulant and flocculant, respectively. Batch coagulation-flocculation experiments were conducted in 500 mL glass beakers. Various doses of alum (50, 100, and 150 mg/L) and PAM (50, 100, and 150 mg/L) were added to the wastewater samples, and the pH of the samples was adjusted to 7 using 1 M HCl or NaOH. The samples were mixed at 150 rpm for 5 minutes, and then gently stirred at 50 rpm for 30 minutes to allow for coagulation and flocculation to occur.

Turbidity, COD, and BOD Analysis

After the coagulation-flocculation process, the treated wastewater samples were allowed to settle for 1 hour. Supernatant samples were collected and analyzed for turbidity, COD, and BOD using the closed reflux colorimetric method and the standard dilution method, respectively (Baird et al., 2017) .

Rheological Properties Analysis

TA-Rheometer type HR-2 Discovery Hybrid was used for Rheological measurements of sludge samples. Peltite plate geometry was selected which is suitable for low viscosity liquids. During all rheological tests, no water was rejected even when imposing a high shear rate. The procedure was started by selecting geometry and choosing the DIN concentric cylinder and then set the system to the zero gap. Then, sludge sample was loaded into the geometry. All test conditions work were selected as: sample intervals 10 point per decades; range of shear rate 0-1200 1/s; temperature 25^{o}C

RESULTS AND DISCUSSION

Composition of fish processing wastewater

The composition of composite fish processing wastewater samples collected from Nizwa fish processing unit is shown in Table 1.

The wastewater from the fish processing plant has relatively high levels of TSS, BOD, COD, and turbidity, which exceed the wastewater reuse and discharge standards of Oman. In a study conducted by Guimarães et al., (2018), the composition of wastewater from a sea food processing unit in Brazil was analyzed. High concentrations of organic matter, total suspended solids, and nitrogen compounds, as well as significant levels of oil and grease, were found in the wastewater.

It can be challenging to compare the composition of fish processing wastewater in Oman with that of other countries due to variations in sampling and analysis methods, as well as differences in the fish species and processing techniques used. However, according to a literature review (Anjum et al. 2018; El-Naggar et al. 2015), fish processing wastewater from other countries may contain similar components to those found in Oman.

Fish processing wastewater from a plant in Pakistan was analyzed in a study by Anjum et al. (2018), which found high levels of total suspended solids, organic matter, and nitrogen compounds. El-Naggar et al. (2015) examined fish processing wastewater from plants in Egypt and found high levels of total suspended solids, organic matter, and oil and grease.

Overall, high levels of organic matter, total suspended solids, nitrogen compounds, and oil and grease characterize fish processing wastewater in Oman and other countries. The specific composition of fish processing wastewater can vary depending on a range of factors.

Turbidity Removal

The results of turbidity removal from fish processing wastewater by alum and PAM are presented in Figure 1 and 2 respectively. It can be observed that both alum and PAM effectively reduced the turbidity of the wastewater samples in a dose-dependent manner. Alum showed higher turbidity removal efficiency compared to PAM at all tested doses. The highest turbidity removal efficiency of 93% was achieved with alum at a dose of 200 mg/L, while PAM achieved a maximum turbidity removal efficiency of 86% at a dose of 100 mg/L.

Table 1. Composition of fish processing wastewater and comparison with wastewater reuse and discharge standards

Parameter	Nizwa Fish Processing Unit	Wastewater Reuse and Discharge Standards in Oman (MD 145-93)
Turbidity (NTU)	100	--
pH	6.5	6-9
BOD (mg/l)	1430	< 20
COD (mg/l)	9743	< 200
Total Suspended Solids(mg/l)	360	< 150

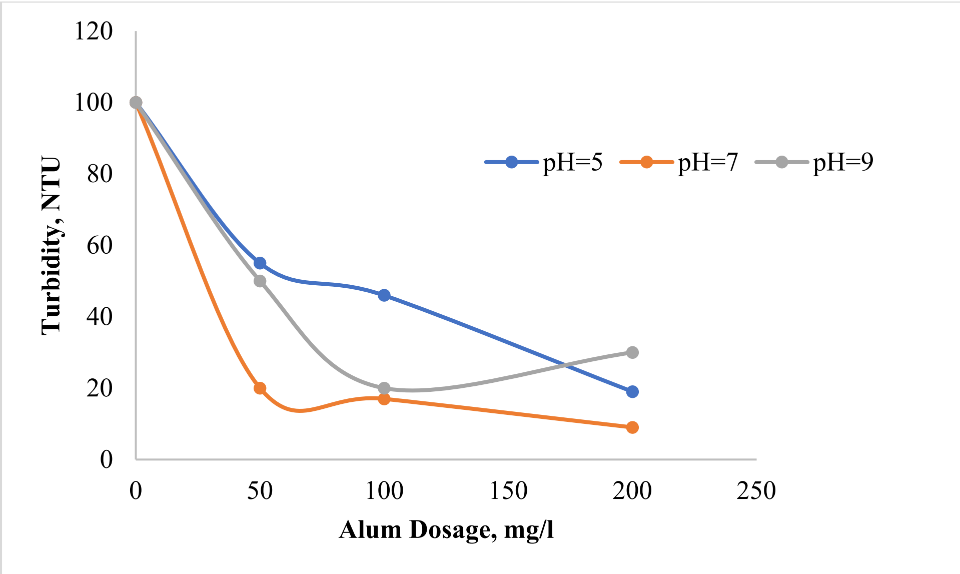

Fig. 1. Effect of Alum dosage and initial pH on turbidity removal

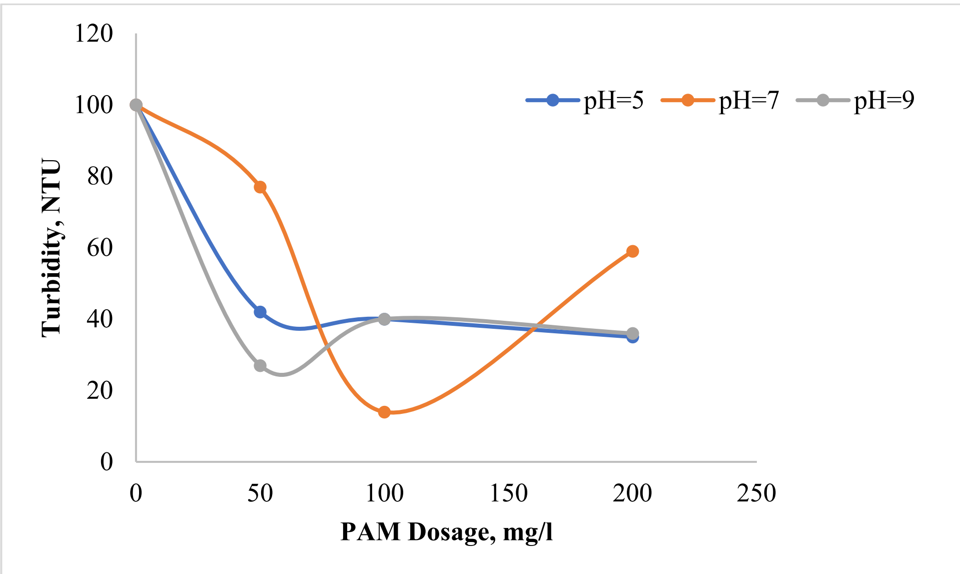

Fig. 2. Effect of PAM dosage and initial pH on turbidity removal

Furthermore, the study also found that the optimal pH for turbidity removal using Alum and PAM was 7. At lower pH values, the efficiency of both coagulants decreased due to the formation of colloidal particles, while at higher pH values, the formation of flocs was inhibited.

These results can be rationalized based on the chemical mechanism of coagulation. Alum works by forming aluminum hydroxide flocs, which neutralize the charge of colloidal particles and cause them to clump together, while PAM works by bridging colloidal particles together to form larger flocs. The optimal pH range for both coagulants correspond to the pH range where the aluminum hydroxide flocs and the PAM bridges are most stable and effective in removing turbidity from wastewater.

The results of turbidity removal from fish processing wastewater by alum and PAM are consistent with previous studies (Iqbal and Zahra, 2018; Rasheed, 2017), which demonstrated the effectiveness of these coagulants in reducing turbidity. Alum showed higher turbidity removal

Table 2. COD and BOD removal by Alum and PAM

Coagulant	Dosage(mg/L)	Percentage of BOD_5 removal			Percentage of COD removal		
		pH 5.0	pH 7.0	pH 9.0	pH 5.0	pH 7.0	pH 9.0
Alum	50	43.684	66.7686	49.128	32.6	51.4	35.6
Alum	100	48.91	72.0945	53.13	36.5	55.5	38.5
Alum	200	58	86.7978	56.994	42.9	63.2	41.3
PAM	50	42.612	63.0015	46.782	31.8	48.5	33.9
PAM	100	52.662	73.6533	53.958	39.3	56.7	39.1
PAM	200	60.032	79.3689	58.098	44.8	61.1	42.1

efficiency compared to PAM, which is in line with previous studies that reported the superior coagulation-flocculation performance of alum (Chowdhury et al., 2017). The higher turbidity removal efficiency of alum can be attributed to its ability to form larger flocs and settle more rapidly, resulting in better clarification of wastewater (Chowdhury et al., 2017).

A study conducted by Omoju and Uzodinma (2020) investigated the effect of varying doses of Alum and PAM on the removal of turbidity from fish processing wastewater. The study found that the efficiency of both coagulants increased with increasing dosage, with Alum being more effective than PAM. However, at higher dosages, the removal efficiency of both coagulants decreased due to the formation of flocs that were too large to settle.

Previous studies have also reported similar findings on the effect of coagulant dosage and pH on turbidity removal from fish processing wastewater. A study by Akpor et al. (2015) found that increasing the dosage of Alum and PAM increased their efficiency in removing turbidity from fish processing wastewater, while a study by Khan and Malik (2016) reported that the optimal pH range for Alum and PAM was within the range of 6-7.

In conclusion, the dosage of Alum and PAM, as well as the pH of the wastewater, can significantly affect their performance in removing turbidity from fish processing wastewater. These findings have been supported by previous studies and can be rationalized based on the chemical mechanism of coagulation.

COD and BOD Removal

Table 2 below summarizes the results of BOD and COD removal from fish processing wastewater by Alum and PAM at different dosages and pH values.

The results in Table 1 show that the effectiveness of both Alum and PAM for the removal of BOD and COD from fish processing wastewater varies with pH and dosage. At all pH values tested, higher dosages of Alum and PAM generally resulted in higher BOD and COD removal efficiencies.

Alum and PAM achieved the highest BOD5 and COD removal efficiencies at a dosage of 200 mg/L and pH 7.0. However, the removal efficiencies varied at different pH values and dosages. When the pH was 5.0, using 200 mg/L of Alum removed 58% of BOD and 43% of COD, while PAM removed 56% of BOD and 45% of COD. At pH 9, using 200 mg/L of Alum removed 58% of BOD and 42% of COD, and PAM removed 58% of BOD and 42% of COD with the same dosage. These results demonstrate that the efficacy of Alum and PAM for BOD_5 and COD removal is highly dependent on the pH and dosage used.

The rationale for the removal of BOD and COD by Alum and PAM is based on their ability to coagulate and flocculate organic and inorganic particles in the wastewater. Alum and PAM form large flocs that settle easily, which can then be removed by sedimentation or filtration. The coagulation and flocculation process can also remove other impurities such as suspended solids, color, and turbidity, resulting in improved water quality.

The results of this study are consistent with previous research on the use of Alum and PAM for the treatment of industrial wastewater. In a study by Maharani et al., (2021) found that PAM was effective for the removal of BOD and COD from fish processing wastewater at a pH of 7.0, with the highest removal efficiencies achieved at a PAM dosage of 20 mg/L. Another study by Hussaini Jagaba, (2018) found that the optimal dosage of Alum for the removal of COD from wastewater was 10 g/L at a pH of 7.0.

Rheological Properties

Rheological experiments were performed on fish processing wastewater before treatment and on each residual settled solid of the treated fish processing wastewater with different concentrations of Alum and PAM at different pH levels. The results are shown in Figure 3 to 5.

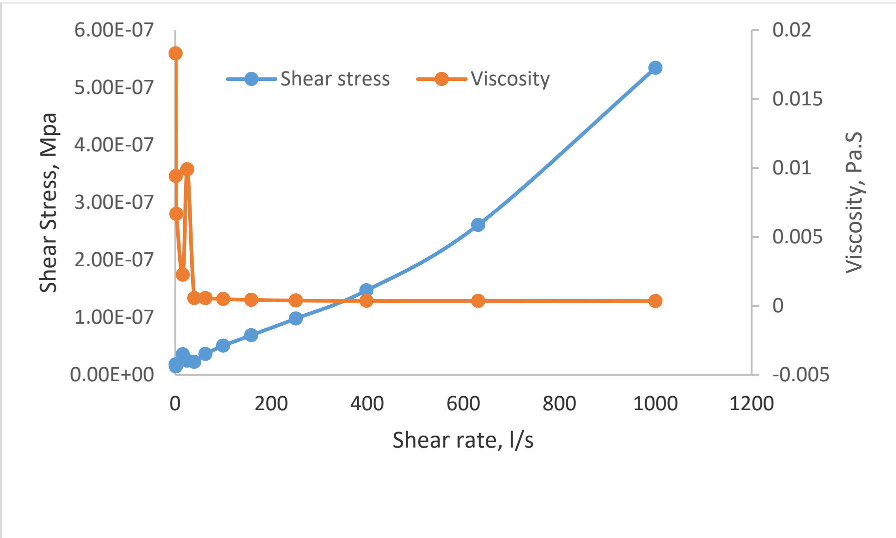

Fig. 3. Shear stress and viscosity of untreated fish processing wastewater

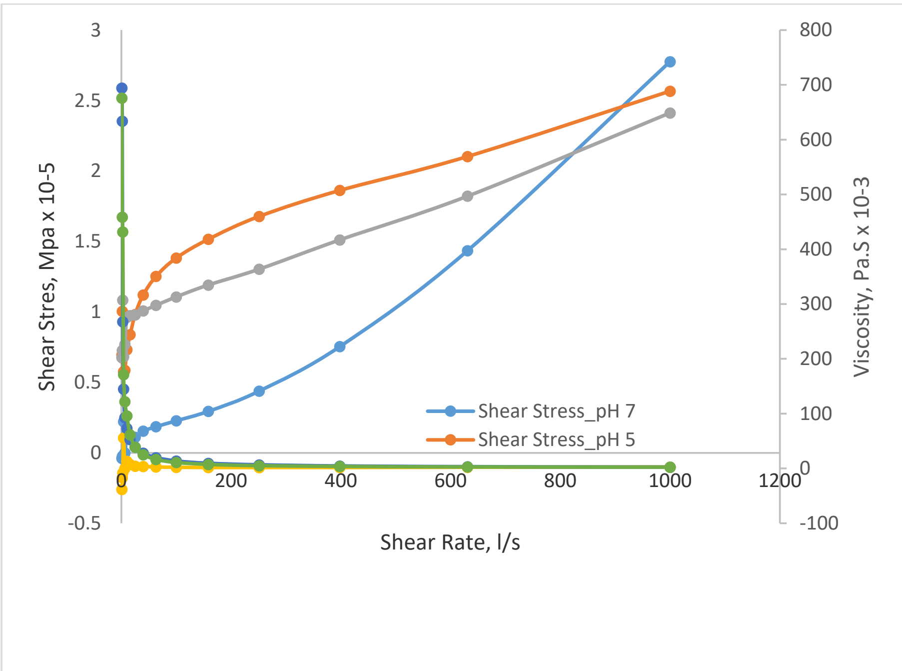

Fig. 4. Shear stress and viscosity of residual settled solids with Alum

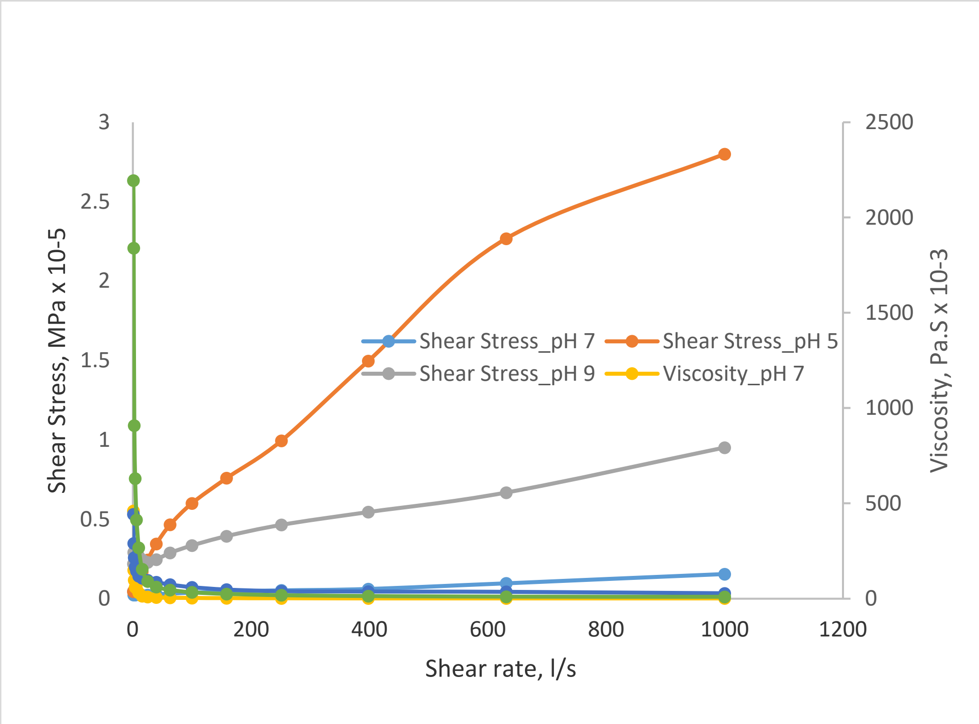

Fig. 5. Shear stress and viscosity of residual settled solids with PAM

The results indicate a non-Newtonian behavior of most tested samples at pH =7 and pH= 9. The shear stress of most samples was following Bingham model as give be (Eq; 1).

$$\tau = \tau_{\circ} + k\gamma \quad (1)$$

The yield stress $\tau_{\circ}$ and k value for the Bingham model are given in Table 4. However, the results of stress of pure fish processing wastewater (with large blood content) showed a shear thickening characterization, this agrees with the work that carried out by Al-Dawery, 2016. The shear stress of some non-Newtonian fluids depends not only on the local strain rate, but also on the history of the fluid. Applied stress causes a fluid to return (partially or fully) to its original shape after being released. both the Bingham plastic and the pseudoplastic are shear thinning, since the viscosity decreases with increasing shear rate, whereas the dilatant fluid is shear thickening. The structural fluid exhibits Newtonian behavior at very low and very high values of shear rate and is shear thinning at intermediate shear rates. Most of test of shear stress of samples at pH=5 shear thinning behavior (Al-Dawery and Reddy 2017).

The results of yield stresses of the rheological tests on the settled solid samples are given in Table 3 . It can be observed that minimum yield stresses were obtained with all samples; this low yield stresses are necessary for better flowing characterization.

From Figure 3 to 5, It can be observed that the viscosity of untreated sample is less compared to residual settled solid of the treated fish processing wastewater. The addition of a coagulant can change the rheological properties of the wastewater by altering its viscosity, yield stress, and shear strength. The effect of coagulation on the rheological properties depends on a number of factors, including the type and concentration of the coagulant used, the characteristics of the wastewater, and the process conditions. In general, chemical coagulation can increase the viscosity of wastewater by causing suspended particles to aggregate and form larger flocs, which

Table 3. Different yield stress and K values for all settled solids

Samples Treated with	Stress (τ_0)	K
Alum at pH=7	9.00E-07	2.00E-09
Alum at pH=5	9.00E-07	2.00E-09
Alum at pH=9	4.00E-09	3.00E-09
PAM at pH=7	3.00E-07	1.00E-09
PAM at pH=7	2.00E-06	3.00E-08
PAM at pH=9	2.00E-06	7.00E-09

are more difficult to move through the water. The addition of coagulant can also increase the yield stress of the wastewater, making it more resistant to flow. This can be beneficial in wastewater treatment processes that rely on sedimentation, as it can help the flocs settle more quickly and efficiently. However, the effect of coagulation on the rheological properties of wastewater is not always straightforward. In some cases, the addition of coagulant can actually decrease the viscosity of the wastewater by breaking up smaller flocs and reducing the resistance to flow. The effect of coagulation on the rheological properties of wastewater is also dependent on the concentration of the coagulant, with higher concentrations generally resulting in more significant changes to the rheology of the wastewater.

CONCLUSION

This study demonstrates that the treatment of fish processing wastewater can be significantly improved through chemical coagulation using Alum and PAM. The key findings include the substantial reduction in turbidity, BOD, and COD of the treated wastewater when employing Alum and PAM. The optimal pH for effective turbidity removal was determined to be 7 using these coagulants. Furthermore, the highest BOD_5 and COD removal efficiencies were achieved at a dosage of 200 mg/L and pH 7.0. It was observed that the efficacy of Alum and PAM in removing BOD5 and COD is greatly influenced by the pH and dosage utilized. Additionally, the residual settled solids from the fish processing wastewater treatment exhibited non-Newtonian behavior and followed the Bingham model for most samples. The results of shear stress indicated low yield stress and limited viscosity, which would reduce friction during pumping processes. This research has important implications for the fishing industry and could help develop more sustainable and efficient treatment practices.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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