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Evaluating Natural and Treated Clay Coagulants for Wastewater Treatment in Agro-Food Industries Related to Meat, Oil, and Fruit Juice Processing

Moustafa M. Abdelraouf [1]*, Amina Shaltout [1], Sally Hosny [1], Hesham M. Abdulla [2], Abeer El Shahawy [1]

[1] *Department of Civil Engineering, Faculty of Engineering, Suez Canal University, P.O. Box 41522, Ismailia, Egypt,*
[2] *Department of Botany and Microbiology, Faculty of Science, Suez Canal University, P.O. Box 41522, Ismailia, Egypt,*

**Corresponding author: Moustafa M. Abdelraouf, Email address: mostafaabdelraouf@eng.suez.edu.eg*
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Abstract

Agro-food industries, such as meat processing, vegetable oil production, and fruit juice manufacturing, produce wastewater with significant environmental impacts due to high levels of pollutants. This study evaluates the effectiveness of natural clay (n.clay) and treated clay (t.clay) coagulants in treating wastewater from these industries. The wastewater was characterized by high levels of chemical oxygen demand (COD), total suspended solids (TSS), turbidity, and color. The n.clay and t.clay were tested for their ability to reduce these pollutants. Results showed that for vegetable oil wastewater, t.clay reduced COD by 54.08%, while n.clay achieved a 40.14% reduction. In meat processing wastewater, t.clay reduced COD by 6.62%, while n.clay showed no reduction. For fruit juice wastewater, n.clay demonstrated better COD reduction (43.91%) than t.clay (20.24%). The cost estimation indicated that treating 1 cubic meter of wastewater with natural clay would cost approximately 10.2 Egyptian pounds. This study highlights the potential of clay-based coagulants as sustainable alternatives to chemical treatments in wastewater management..

Keywords: *Agro-food wastewater, Clay coagulants, Wastewater treatment, Natural and treated clay, Sustainable wastewater management.*

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1. Introduction

Agro-food wastewater presents significant challenges due to the high concentrations of organic matter, fats, oils, and suspended solids it contains. Without proper treatment, these pollutants can contribute to severe environmental problems, including eutrophication, oxygen depletion in aquatic ecosystems, and overall water quality degradation (Valta et al., 2017). The large volumes of wastewater generated by industries such as meat processing, vegetable oil production, and fruit juice manufacturing make it imperative to implement efficient treatment methods to mitigate these environmental risks and ensure sustainable wastewater management in agro-industrial operations.

Conventional wastewater treatment processes often involve chemical coagulants like aluminum sulfate (alum) or ferric chloride to enhance the removal of suspended particles and reduce turbidity (Sultana, Karmaker, Saifullah, Galal

Uddin, & Moniruzzaman, 2021). While effective, these chemicals present several drawbacks. Residual chemical compounds can cause secondary pollution, increase sludge production, and significantly raise the operational costs of treatment facilities. Additionally, concerns about the health and environmental impacts of residual metal coagulants have led to a search for greener alternatives (Amor, Marchão, Lucas, & Peres, 2019).

Among the more sustainable options, clay-based coagulants have gained increasing attention due to their natural abundance, low cost, and reduced environmental footprint. Natural clays, such as bentonite and kaolinite, possess a high surface area and strong adsorptive properties, making them ideal candidates for removing contaminants from wastewater streams (Ferasat, Panahi, & Mokhtarani, 2020). (Ferasat et al., 2020). These materials can be used either in their raw form or after undergoing chemical or physical treatment to enhance their coagulation efficiency (Sultana et al., 2021). Several studies have demonstrated that clay-based coagulants can effectively reduce turbidity, total suspended solids (TSS), and chemical oxygen demand (COD) in wastewater, positioning them as promising alternatives for large-scale applications (Sahu & Chaudhari, 2014).

The agro-food industry, with its complex wastewater composition, presents unique challenges for treatment. For example, meat processing effluents contain high levels of fats, proteins, and organic matter, which can be difficult to manage using conventional treatment methods (Gharby, 2022). Similarly, wastewater from vegetable oil and fruit juice production is characterized by high concentrations of oils, sugars, and suspended solids, requiring tailored treatment approaches (Kurup, Adhikari, & Zisu, 2019). The use of natural and treated clay coagulants can offer an opportunity to develop more sustainable and cost-effective solutions, reducing both pollutant levels and operational costs for wastewater treatment in agro-food industries.

This study aims to assess the effectiveness of natural and treated clay coagulants in treating wastewater from three major agro-food sectors—meat processing, vegetable oil production, and fruit juice manufacturing. By comparing the performance of these coagulants in reducing COD, TSS, turbidity, and color, this research seeks to identify the most efficient and sustainable treatment approach for different types of agro-food wastewaters. The findings of this study add to the research on eco-friendly wastewater treatment methods and provide ideas to help lower the environmental impact of agro-food industries.

2. Materials and Methods

Lately, the disconnection, that exists in the modern architectural spaces, between the indoor and outdoor, has been noticed by architects, especially after the proven impacts on humans' well-being, as spending most of the time indoors without any contact with the natural world, leads to severe damages on the humans' psychological and physiological health. Therefore, adopting a method that can connect the built environment is a must, one of these tools is biophilic design. That's why, understanding the concept, the origin, definition, aims and benefits, and practice in the architecture field is required to assist in spreading the awareness regarding a healthy environment that is not just considered as a place to inhabit, but a pleasant experience of remarkable memories to evolve positive attachments.

2.1 **Sampling and Study Sites**

Wastewater samples were collected from three agro-food industries: meat processing (Atyab Factory), vegetable oil processing (Arma Factory), and fruit juice production (Fresh Factory); all located at the 10th Ramadan City, and Ismailia Industrial Zone Egypt. Six replicate samples from each facility were taken over six-month period to account for variability in the effluent characteristics. The samples were collected in clean, pre-labeled polyethylene containers, preserved with necessary precautions, and transported to the laboratory under refrigerated conditions.

2.2 **Physicochemical Analysis**

All the wastewater analyses, before and after treatment, were performed according to the standard methods. The pH was measured using a digital pH meter (Hanna Instruments), and electrical conductivity (E.C) was determined using a calibrated conductivity meter (Model 3100, Eutech Instruments). Redox potential was evaluated with an ORP meter, while salinity was measured using a digital salinity meter. Chemical Oxygen Demand (COD) was measured using the dichromate method (APHA Standard Methods 5220C). Total Suspended Solids (TSS) were determined by filtering a known volume of sample through a pre-weighed glass fiber filter, drying at 103-105°C, and weighing the residue (APHA Standard Methods 2540D). Turbidity was measured using a nephelometric method with a turbidity meter (APHA Standard Methods 2130B). Color was assessed using a spectrophotometer at a wavelength of 455 nm (APHA Standard Methods 2120C). The results were analyzed to determine the optimal conditions for maximum removal efficiencies of the targeted pollutants using the desirability function method.

2.3 **Preparation of coagulant and coagulation batch experiment (preparation of coagulants):**

Natural clay

Natural clay in its solid form was collected from Masr Company for Mineralization and Bentonite, Burg El-Arab, Egypt. The small pieces of clay were washed with distilled water to eliminate any non-adhesive impurities, dried in an oven at 80 ◦C for 24 h to remove any moisture, then kept in a desiccator, and finally crushed to 0.25mm particle size to be employed (ElBastamy et al., 2021)

Treated clay (Thermal treated clay)

Thermal treatment of clay used in wastewater treatment provides several key advantages that enhance the clay's ability to remove contaminants. It is significantly increasing the porosity of clay, creating more surface area for adsorption which makes the clay more effective at capturing pollutants like organic compounds from wastewater. This type of treatment also drives off excess moisture, making the clay more stable in wastewater treatment applications. This structural stability ensures that the clay does not degrade or swell in the presence of water, and be more stable in extreme environmental conditions, such as high acidity or alkalinity which allows the clay to be used in a wider range of wastewater types. Treated samples used in this paper prepared by heating up the raw clay minerals to the desired temperature (800 °C) for a specified period of time (3 h). (Rusmin et al., 2016)

Coagulation Experiment

To study the coagulation process with natural clay (n.clay) and treated clay (t.clay), experiments were conducted by using a standard jar-test apparatus (Model & Country of origin) with 1 lit. beaker. Each coagulant (4 g) was added to 500 mL of wastewater from the three industries mentioned above, stirred for 90 sec at 300 rpm for rapid mixing (coagulation), followed by 20 min at 30 rpm for slow mixing (flocculation), and then allowed to settle for 30 min (sedimentation). The changes in the characteristics of the three wastewater types were evaluated based on pH, turbidity, COD, TSS, and color. All the experiments were performed in triplicates, and the measurements were according to the APHA standards described above.

2.4 Statistical Analysis

Data were expressed as means (ẋ), standard deviations (SD), and ± standard error of the mean (SEM) for each parameter, based on six replicate measurements per industry. The data were analyzed using one-way ANOVA to assess significant differences between wastewater characteristics from the three types of agro-food industries. A post-hoc Tukey's HSD, (Honestly Significant Difference), test was applied following one-way ANOVA (Pereira, Afonso, & Medeiros, 2015), to determine which wastewater characteristics varied significantly between the three agro-food industries (meat processing, vegetable oil, and fruit juices). The test compares all possible pairs of means to identify where significant differences lie. The "HSD" represents the critical value or threshold beyond which differences between group means are considered statistically significant for each wastewater parameter. Statistically significant differences were observed between the wastewater types at $p < 0.05$).

3. Results

3.1 Agro-food wastewater characterization

The wastewater characteristics from three different agro-food industries—meat processing (Atyab Factory), vegetable oil (Arma Factory), and fruit juices (Fresh Factory)—were analyzed and compared, as presented in Table 1. The results reveal significant variations in the physicochemical properties among the different types of wastewaters. For pH, the vegetable oil wastewater exhibited the highest mean value (7.89 ± 0.400), while the meat processing wastewater had the lowest (5.19 ± 0.403). Electrical conductivity (E.C) also varied, with the meat processing wastewater showing the highest conductivity (1.5815 ± 0.128 ms/cm), indicating a higher concentration of dissolved ions. The color and turbidity measurements highlighted substantial differences, particularly in vegetable oil wastewater, which showed the highest mean color value (2358.33 ± 855.805 pt-co) and a high degree of variability, as evidenced by the large SEM. Similarly, high variability was observed in the total suspended solids (T.S.S) of meat processing wastewater (3115.23 ± 1150.556 ppm) and the chemical oxygen demand (COD) across all types of wastewaters, especially in the fruit juices wastewater (2426.1 ± 769.434 ppm). These results emphasize the complexity of wastewater treatment requirements in agro-food industries, particularly due to the high standard error of the mean (SEM) observed in some parameters, which suggests significant fluctuations in the wastewater characteristics. The variability in agro-food wastewater characteristics is shown in Table (1) and Fig. (1), highlighting the challenges in standardizing treatment processes.

Values are presented as mean of seven samples, ± SEM (Standard Error of the Mean).

[a] International Standards for Safe Disposal are based on WHO, World Health Organization (2006), guidelines on safe disposal limits and EPA, Environmental Protection Agency, (Manual, 1988) standards for wastewater disposal.

[b] values can change depending on the specific application or environmental context.

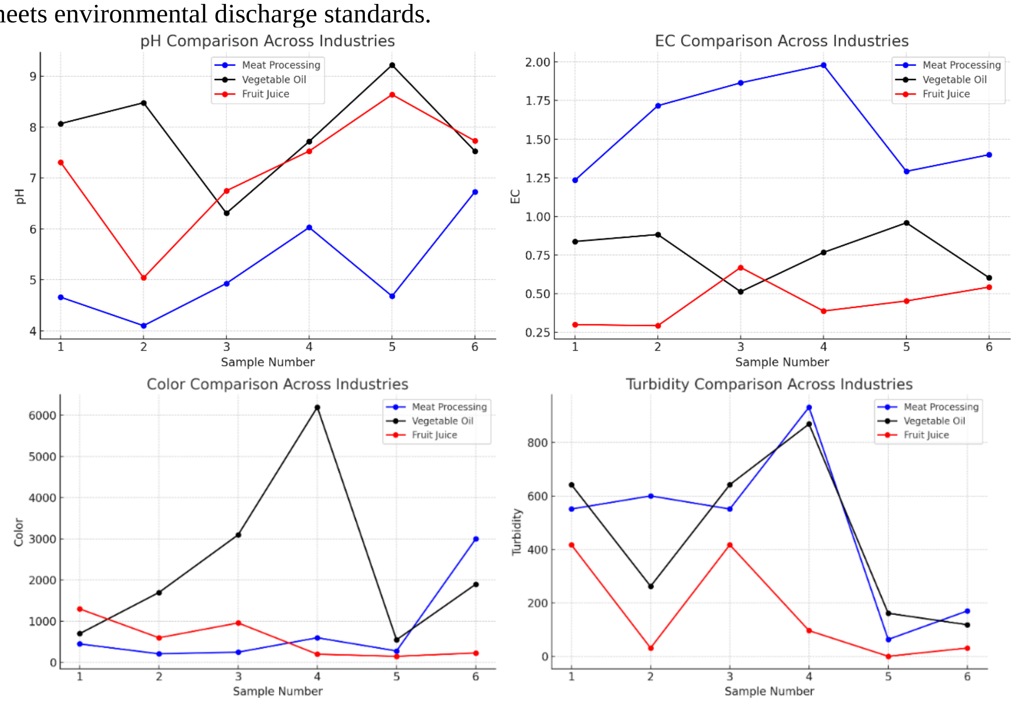
Table 1. Wastewater characteristics from agro-food industries, compared to the international standards for safe disposal.

Parameter	Agro-food wastewater			International Standards for Safe Disposal [a]
	Meat Processing (Atyab Factory)	Vegetable Oil (Arma Factory)	Fruit Juices (Fresh Factory)	
pH	5.19 ± 0.403	7.89 ± 0.400	7.17 ± 0.495	6.0 – 9.0 (WHO, EPA)
E.C. (ms/cm)	1.5815 ± 0.128	0.7605 ± 0.070	0.4412 ± 0.060	< 2.0 ms/cm (WHO, EPA)
Color (pt-co)	798.33 ± 444.353	2358.33 ± 855.805	573.33 ± 192.764	< 300 pt-co (EPA)
Turbidity (NTU)	463.2 ± 156.895	410.4 ± 147.254	136 ± 95.778	< 30 NTU (WHO)
Redox (MV)	103.62 ± 26.812	-44.48 ± 27.678	-27.53 ± 19.192	Varies (depends on context) [b]
Salinity (ppm)	765.2 ± 80.661	360.6 ± 40.612	249.68 ± 30.582	< 1000 ppm (WHO)
T.S.S (ppm)	3115.23 ± 1150.556	474 ± 341.114	409.98 ± 187.986	< 500 ppm (EPA)
COD (ppm)	2447.5 ± 563.594	1690.833 ± 217.526	2426.1 ± 769.434	< 250 ppm (EPA)

The ANOVA results indicate significant differences ($p < 0.05$) in wastewater characteristics among the three agro-food industries (meat processing, vegetable oil, and fruit juice) for several parameters. Specifically, pH, electrical conductivity, and redox potential showed highly significant differences with p-values of 0.00, suggesting substantial variation in effluent characteristics between industries. For color, turbidity, and COD no significant differences were observed ($p > 0.05$), indicating more consistent behavior across the three industries for these parameters. The post-hoc Tukey test confirmed no statistically significant differences in Color, COD, and Turbidity between the three agro-food industries. The mean differences between industries were not large enough to be considered statistically significant ($p > 0.05$) for these parameters (Fig. 2).

The ANOVA results suggest that COD, Turbidity, and Color levels are elevated across all agro-food industries, with no significant variation between them (Table 2).

The results from the Tukey test confirmed that for six of the parameters, there were statistically significant differences between industries (Fig. 2). For the three parameters: color, turbidity, and COD, the Tukey test indicated no statistically significant differences, as the differences between the means of the paired industries were too small to be considered significant ($p > 0.05$). This highlights the consistent presence of these pollutants in the wastewater, from the three industries, emphasizing the potential of applying coagulation treatment to reduce these key pollutants. Coagulation can play a key role in treating these types of wastewaters, ensuring that color, turbidity, and COD are minimized and that the effluent meets environmental discharge standards.



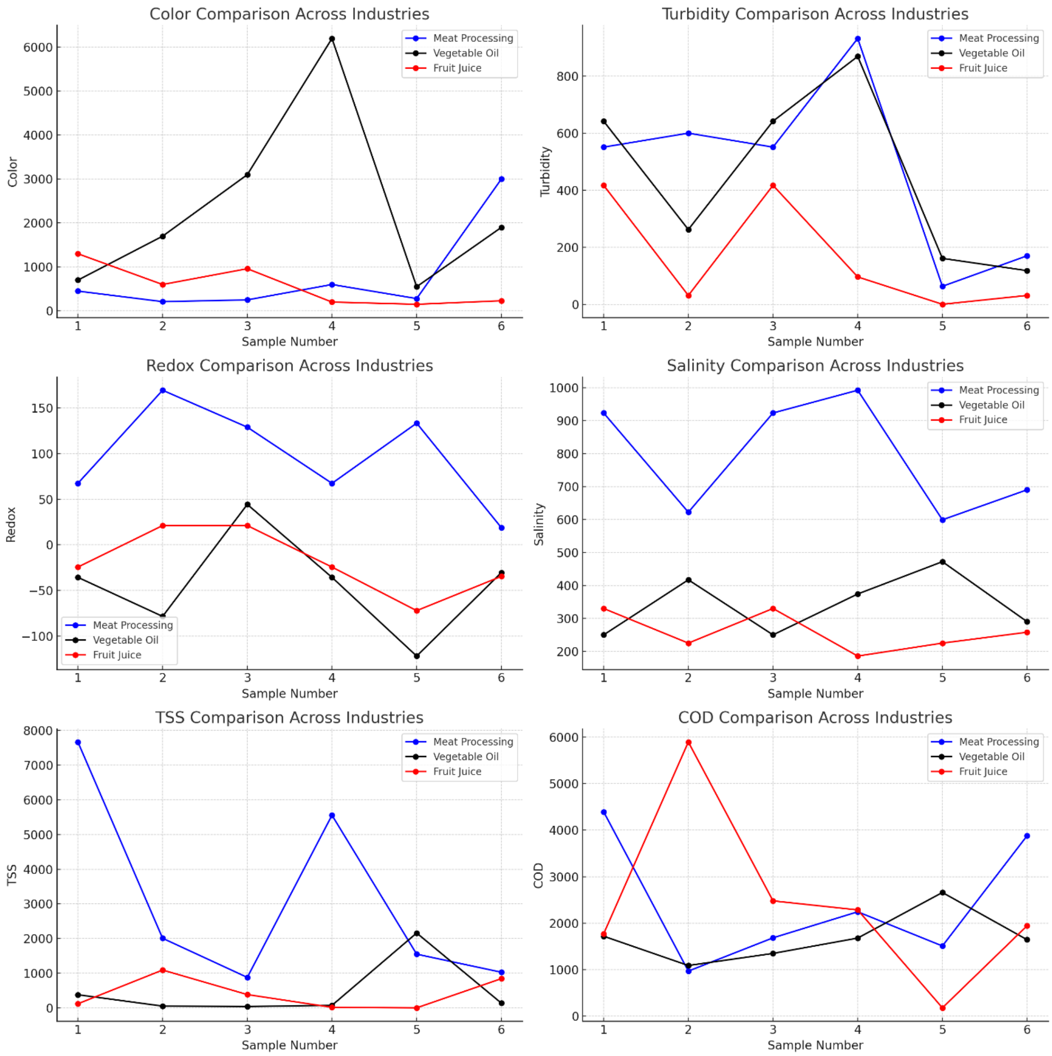


Fig. 1 Comparison of key wastewater parameters across agro-food industries

Table 2. ANOVA results for the agro-food wastewaters

Parameter	F-Statistic	P-Value
pH	10.34	0
EC	41.61	0
Color	2.93	0.08
Turbidity	2.29	0.14
Redox	13.68	0
Salinity	34.87	0
TSS	4.85	0.02
COD	0.58	0.57

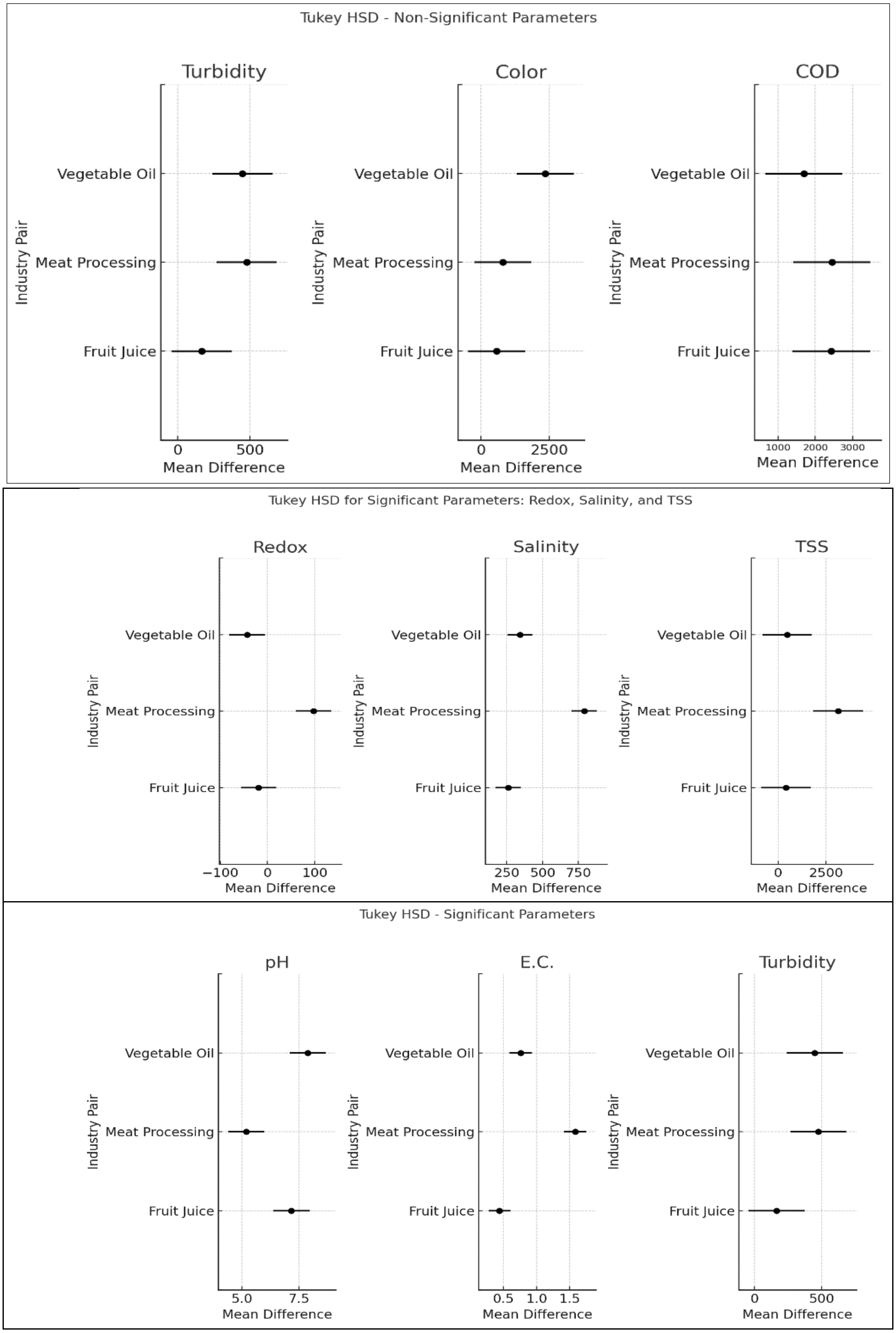


Fig. 2 Tukey HSD test for differences in wastewater parameters across the agro-food industries

[Each horizontal line represents the mean difference between the paired industries for each parameter. The overlapping position emphasizes that these differences are not significant for turbidity, color and COD].

3.2 **Effectiveness of Natural and Treated Clay in Wastewater Coagulation**

In this study, natural clay (n.clay) and treated clay (t.clay) were applied as safe coagulants to treat wastewater from the three agro-food industries: meat processing, vegetable oil processing, and fruit juice production. The coagulation efficiency was evaluated by measuring key parameters such as pH, turbidity, chemical oxygen demand (COD), total suspended solids (TSS), and color before and after treatment.

3.2.1 **Vegetable Oil Processing Wastewater (ARMA)**

The coagulation treatment resulted in notable improvements across all measured parameters (Fig. 3). The pH remained relatively stable after treatment, with only a slight reduction observed in both n.clay (7.78) and t.clay (8.105) compared to the control (8.48). COD values showed significant reductions, with the n.clay reducing COD to 3702.5 mg/L, and t.clay achieving a higher reduction to 2840 mg/L. Turbidity did not significantly changed, with n.clay performing slightly better (181 NTU) compared to t.clay (183.5 NTU), compared to the starting level (179.5 NTU) before coagulation. TSS values were significantly reduced to 0.34075 g/L using n.clay, while t.clay achieved a TSS of 0.667 g/L. Color was notably decreased as well, with n.clay and t.clay showing improvements (200 -250 pt-co), compared to the control (400 pt-co).

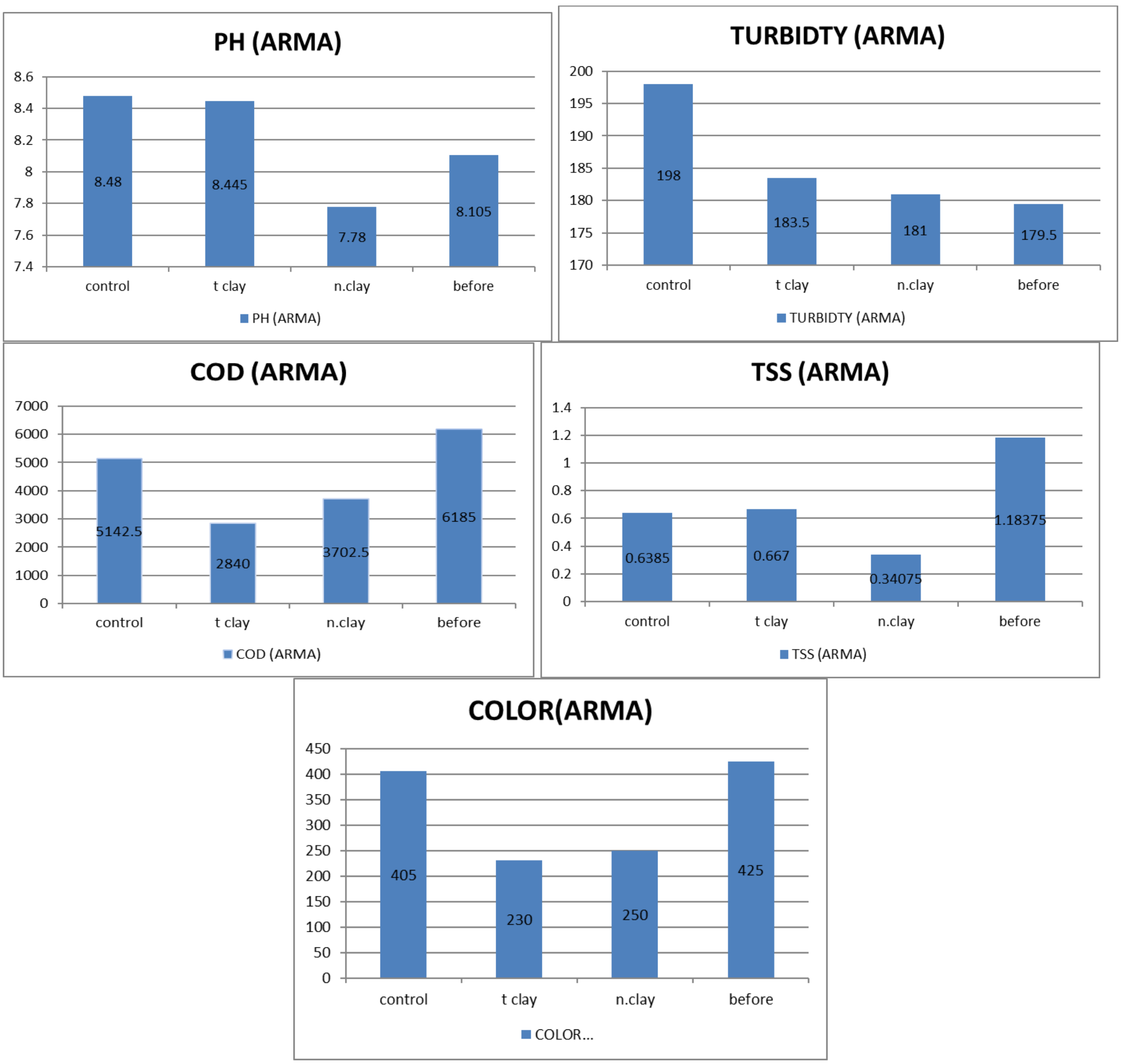


Fig. 3 Effectiveness of natural and treated clay in the coagulation process for vegetable oil wastewater treatment.

3.2.2 **Meat Processing Wastewater (ATYAB)**

In the meat processing wastewater (Fig. 2), the coagulation treatment effectively reduced COD and turbidity levels. The pH saw a marginal decline from 5.4 in the control to 5.27 and 5.37 for n.clay and t.clay, respectively. COD reductions were significant, with t.clays lowering the COD from 2042.5 mg/L to a maximum of 1907.5 mg/L. However, n.clay was not efficient, resulting in almost no COD reduction, being 2042.5 mg/L. Turbidity showed a sharp decrease, particularly with n.clay, which lowered the value from 19 NTU to 3 NTU, while t.clay achieved a reduction to 6 NTU. TSS was also greatly reduced by both clays, with n.clay being more effective (0.34075 g/L) than t.clay (0.667 g/L).

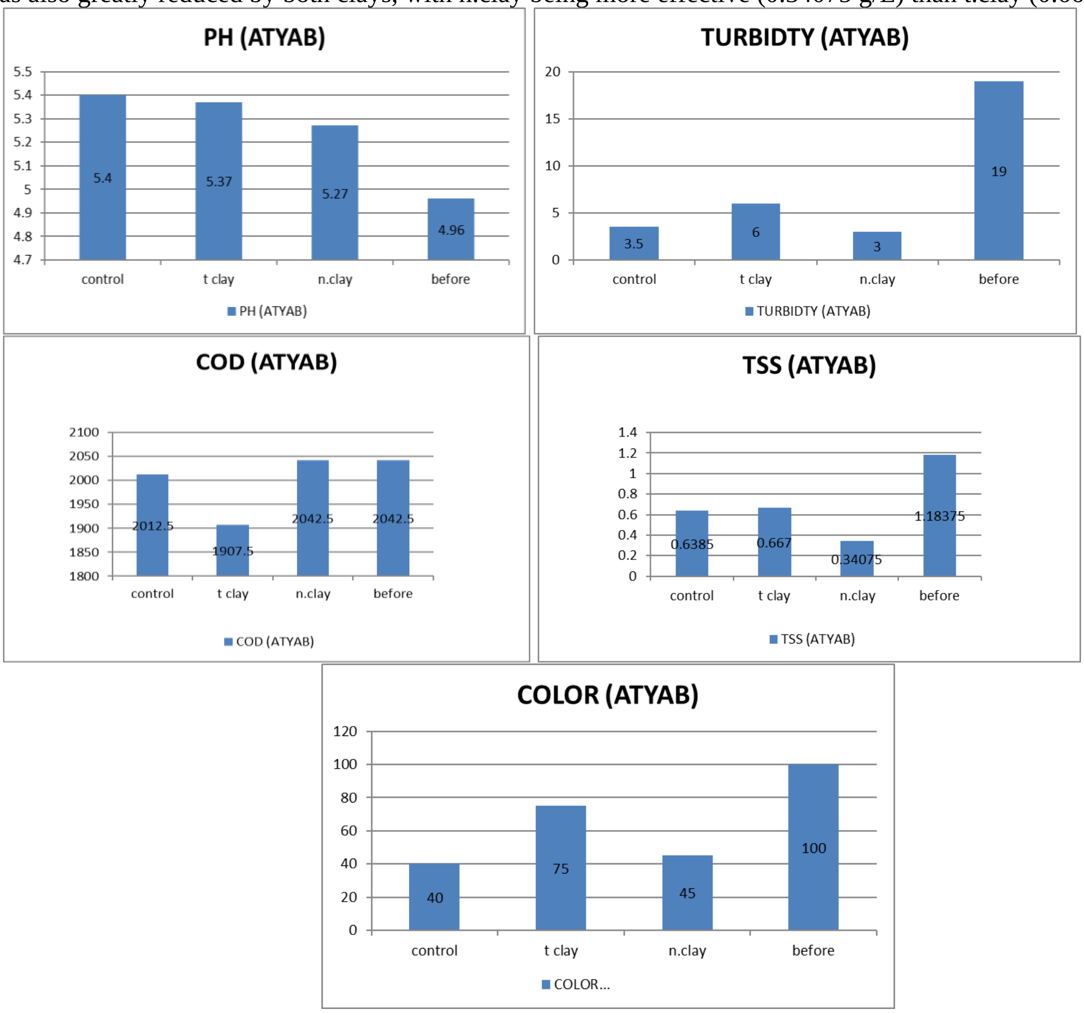


Fig. 4 Effectiveness of natural and treated clay in the coagulation for meat processing wastewater treatment

3.2.3 **Fruit Juice Production Wastewater (FRESH)**

For fruit juice wastewater, the coagulation process showed variable influences, particularly on turbidity, and color (Fig. 5). pH values slightly increased post-treatment, with n.clay achieving a pH of 6.155 compared to 5.435 for t.clay. COD was slightly reduced from 971.332 mg/L to 774.63 mg/L and 544.665 mg/L for t.clay and n.clay, respectively. Turbidity levels were unexpectedly increased by t.clay from 125 NTU to 339.5 NTU, while n.clay increased turbidity to 161 NTU. Similarly, color was negatively affected, with both clays demonstrating considerable increase up to 200 pt-co. However, TSS was significantly lowered by t.clay and n.clay to 1.425 and 0.665, respectively.

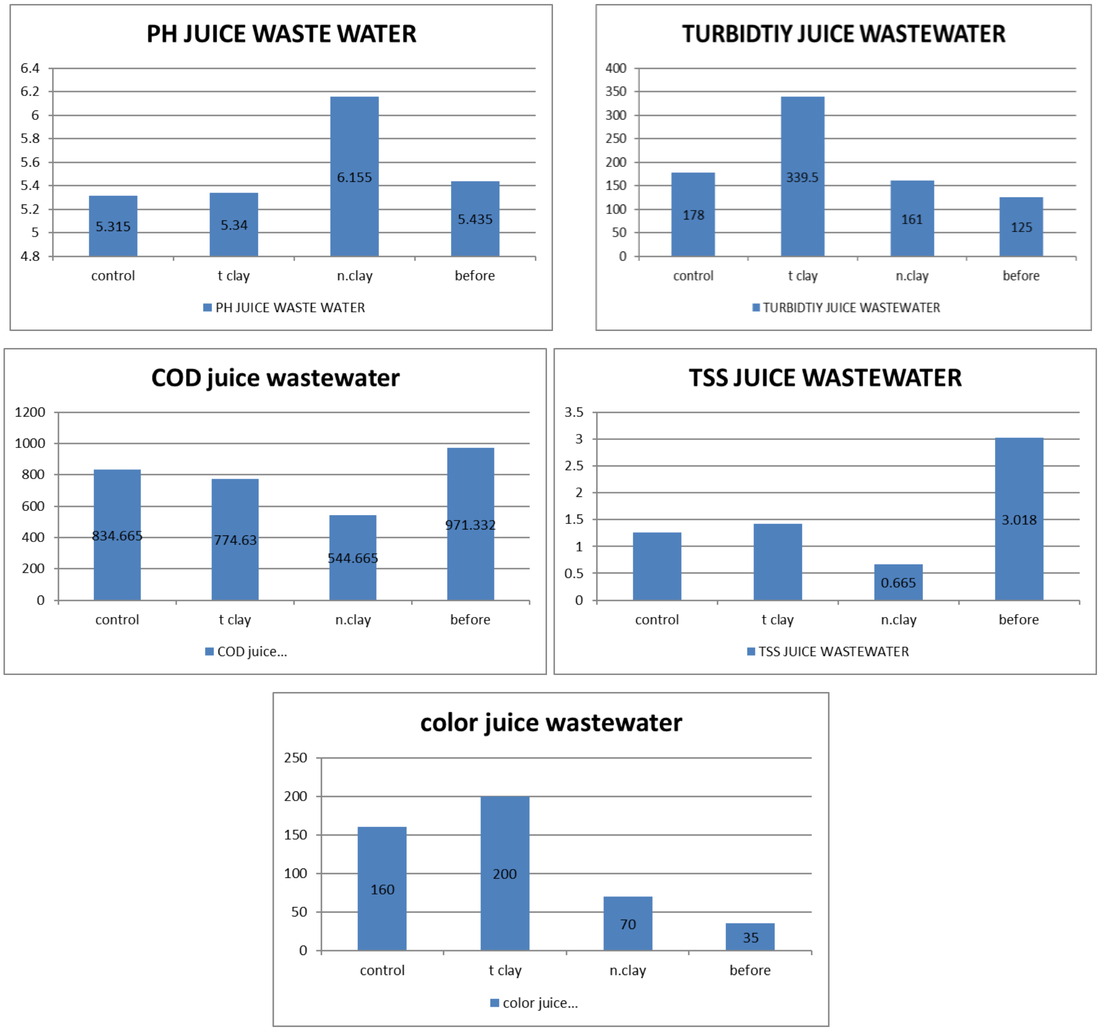


Fig. 5 Effectiveness of natural and treated clay in the coagulation for Fruit Juice Production wastewater treatment.

Overall, the n.clay acheived 40 and 44% COD removal from vegetable oil and fruit juice wastewaters, respectively. While, the t.clay performed better only with vegetable oil wastewater (55% reduction). Table (3) shows the initial COD, the final COD after treatment, and the percentage of COD reduction efficiency for both types of clay in each wastewater type.

Table 3 COD reduction efficiency for natural and treated clays in the three wastewater types

Wastewater Type	Initial COD (mg/L)	Final COD (t.clay) (mg/L)	Efficiency (t.clay) (%)	Final COD (n.clay) (mg/L)	Efficiency (n.clay) (%)
Vegetable Oil	6185	2840	54.08%	3702.5	40.14%
Meat Processing	2042.5	1907.5	6.62%	2042.5	0%
Fruit Juice	971.332	774.63	20.24%	544.665	43.91%

3.3 **Theoretical cost estimation of the coagulation process using natural clay:**

To estimate the cost of treating 1 cubic meter of fruit juice wastewater per day using natural clay, the jar-test setup was scaled to an operational level. Each test used 8 g of natural clay per liter (4 g for 500 mL of wastewater). Therefore, for 1 cubic meter (1,000 liters), the required dosage is 8 kg of clay.

Cost of Natural Clay:

- 1,000 kg of natural clay costs 400 Egyptian pounds (local market price, at Sept. 2024).

Material Cost Calculation:

- In the experiment, 8 g of clay is used per liter of wastewater.

- For 1 cubic meter (1,000 liters) of wastewater, would require:
  8 g/L × 1,000 L = 8,000 g = 8 kg of clay per cubic meter.
- The cost of 8 kg of natural clay (since 1,000 kg costs 400 EGP) is:
  (400 EGP / 1,000 kg) × 8 kg = 3.2 EGP per cubic meter.

Operational and Environmental Costs:

Operational and environmental costs are generally minimal for natural clay, estimated at:

- Operational cost: 5 EGP per cubic meter (for labor, energy, etc.).
- Environmental/Regulatory cost: 2 EGP per cubic meter (for disposal or environmental management).

Total Cost Per Cubic Meter:

$$Total\ Cost = Material\ Cost + Operational\ Cost + Environmental\ Cost$$
$$Total\ Cost = 3.2\ EGP + 5\ EGP + 2\ EGP = 10.2\ EGP\ per\ cubic\ meter$$

Therefore, the theoretical cost of treating 1 cubic meter of wastewater daily using natural clay is approximately 10.2 Egyptian pounds.

4. Discussion

4.1 Differences between agro-food wastewaters

The post-hoc Tukey test results confirmed the significant differences in wastewater characteristics among the three agro-food industries, aligning with existing research on the variability in wastewater properties. For example, the higher pH in vegetable oil wastewater compared to meat processing wastewater is consistent with previous studies highlighting the alkaline nature of effluents from oil-based industries due to oil processing activities (Gharby, 2022). Similarly, the significantly elevated COD levels in fruit juice wastewater are supported by the findings of other research, which attributes this to the high organic load from fruit sugars and pulp residues in the effluent (Valta et al., 2017). Such variations underscore the need for industry-specific treatment strategies, as noted in studies that emphasize tailored treatment solutions for differing wastewater characteristics, including biological treatment for high organic load effluents and pH adjustments for alkaline streams (Kurup et al., 2019). These findings confirm the importance of using customized approaches to optimize treatment efficiency and ensure regulatory compliance across different agro-food sectors.

Comprehensive reviews have highlighted the ongoing evolution of treatment technologies, emphasizing the need for flexible and effective strategies to manage the complex wastewater streams produced by agro-food industries (Abdulla et al., 2023). Green coagulants offer a promising solution to the challenges of agro-food wastewater treatment. They are effective in reducing turbidity and suspended solids, while being more sustainable and environmentally friendly. These coagulants minimize chemical residues, reduce the ecological footprint, and have proven effective in treating complex effluents, meeting regulatory standards, and aiding in waste valorization (Martins et al., 2022).

4.2 Effectiveness of Natural and Treated Clay in Wastewater Coagulation

The coagulation experiments using natural clay (n.clay) and treated clay (t.clay) as coagulants for wastewater treatment in agro-food industries demonstrated varying degrees of efficiency across different wastewater types (vegetable oil processing, meat processing, and fruit juice production).

For **vegetable oil wastewater**, both natural and treated clays showed substantial improvements in wastewater quality. The most notable reduction was in COD, with t.clay achieving a greater reduction (from 5202.5 mg/L to 2340 mg/L) compared to n.clay. Additionally, turbidity and TSS were significantly lowered, with n.clay better than t.clay in turbidity reduction. These results align with studies that highlight the effectiveness of clay-based coagulants in treating oily wastewater due to their high surface area and adsorptive properties (Sultana et al., 2021).

In the case of **meat processing wastewater**, t.clay showed better performance in COD reduction, lowering it from 2042.5 mg/L to 1907.5 mg/L, while n.clay demonstrated limited effectiveness in COD removal. However, n.clay was more efficient in reducing turbidity (from 19 NTU to 3 NTU), making it suitable for applications where turbidity is the key parameter. The higher performance of natural clay in turbidity reduction may be due to its ability to form charge neutralization and bridging (Ferasat et al., 2020). This mechanism leads to larger and more stable flocs, which facilitates easier removal of suspended particles during sedimentation.

For **fruit juice wastewater**, unexpected increase in turbidity and color after applying both clays. Fruit juice wastewater is rich in organic materials like sugars and pulp, which can interact with the clays and form colloidal suspensions, leading to increased turbidity and color. Sugars and pulp may prevent the formation of stable flocs, contributing to higher levels of suspended solids and relevant colors(Sahu & Chaudhari, 2014). The complex interactions between organic matter and coagulants are known to affect coagulation efficiency, as detailed in research on agro-food wastewater treatments (Amor et al., 2019).

The results of the coagulation experiment demonstrate that both natural and treated clay are effective coagulants for agro-food wastewater treatment. Overall, natural clay exhibited slightly better performance across most parameters, with the exception of reducing COD levels from meat and oil processing wastewaters. This may be attributed to its better particle interaction and surface area for adsorbing contaminants. The natural clays can enhance particle interaction and surface area, improving the removal efficiency of contaminants (Sultana et al., 2021). However, treated clay still proved highly effective and may offer additional benefits in other contexts, such as enhanced durability or lower operational costs.

COD (Chemical Oxygen Demand) is a preferred indicator of coagulation performance because it captures both biodegradable and non-biodegradable organic pollutants, offering a more comprehensive metric than parameters like turbidity or color (Hu, Chandran, Smets, & Grasso, 2002). It directly reflects the organic load in wastewater and is essential for meeting regulatory discharge limits (Manual, 1988). COD reduction also correlates with improved effluent quality, reducing the risk of oxygen depletion and environmental harm, making COD a key measure of both treatment efficiency and environmental sustainability (Metcalf et al., 2007). The 44 - 55% reductions in COD observed for fruit juice and vegetable oil processing align with previous research that reported significant improvements in wastewater quality through coagulation processes using clay-based coagulants. Studies have shown that natural clay coagulants can achieve up to 46.72% COD removal, highlighting their suitability for large-scale applications (Sultana et al., 2021).

The theoretical treatment total cost using natural clay is 10.2 EGP per cubic meter for both vegetable oil and fruit juice wastewater. This low cost makes natural clay an economical choice for wastewater treatment. However, considering the higher COD removal efficiency of natural clay in fruit juice wastewater compared to vegetable oil wastewater, the cost-effectiveness is higher in fruit juice applications. For vegetable oil wastewater, additional treatment steps will be necessary to meet COD standards, potentially increasing the overall cost.

In conclusion, the effectiveness of both coagulants in reducing turbidity, TSS, and COD indicates their suitability for large-scale application in agro-food wastewater treatment. These improvements highlight the potential of using green and sustainable materials like clays as alternatives to chemical coagulants, thereby reducing the environmental footprint of wastewater treatment processes in the agro-food industry. This study emphasizes the importance of selecting appropriate coagulants based on the specific characteristics of the wastewater to be treated. The use of natural and treated clays could be further optimized by adjusting parameters such as dosing and mixing times to maximize treatment efficiency.

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