IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Comparative Study Of Fenton Process And Coagulation – Flocculation Process For Dye Removal Efficiency

Mrs. Swara Bambade; Mrs. Resma B Vijay
Mr. Aman Sharma; Mr. Atharva Dhere; Mis. Rutuja Wadile;

Assistant Professor, Assistant Professor, BE Student; BE Student, BE Student.
Department of Civil Engineering
New Horizon Institute of Technology and Management, Thane, Maharashtra, India

ABSTRACT

Textile Effluent is notoriously difficult to treat because the chemicals are designed to be stable and resist fading, which makes them highly toxic to aquatic ecosystems. To tackle this issue, this project directly compares two chemical treatment methods: coagulation-flocculation and the Fenton process. For the coagulation-flocculation stage, we used different chemical dosages to find the ideal coagulant dose and pH levels needed to separate the dye from the water. For the Fenton process, we conducted experiments to test different ratios of ferrous oxide(fe2so4) and hydrogen peroxide(H2O2) with lime hydrate (Ca (OH)2) to see how effectively the hydroxyl radicals could break down the dye molecules. We evaluated both methods based on COD and TOC levels reduction. Based on existing research, coagulation is incredibly fast and great at stripping color out of the dye water, but it just transfers the pollution into a heavy sludge rather than destroying it. The Fenton process, on the other hand, degrades the chemical structure of the dye, but is expensive and require technical personnel for operating at a highly acidic ph.

Keywords: Dye removal, Coagulation-flocculation, Fenton process, Ph, Chemical Oxygen Demand (COD), Total Organic Carbon (TOC).

1. INTRODUCTION:

The textile industry is a major economic driver, but it leaves behind a massive environmental footprint in the form of coloured wastewater. Every year, thousands of tons of synthetic dyes end up in waterways. They block sunlight from reaching aquatic plants and disrupt local ecosystems. The real headache for treatment plants is that these dyes are specifically engineered to hold up against washing, sweat, and light, which ironically makes them resistant to standard biological treatment methods. When microbes can't break them down, plants start looking for chemical alternatives.

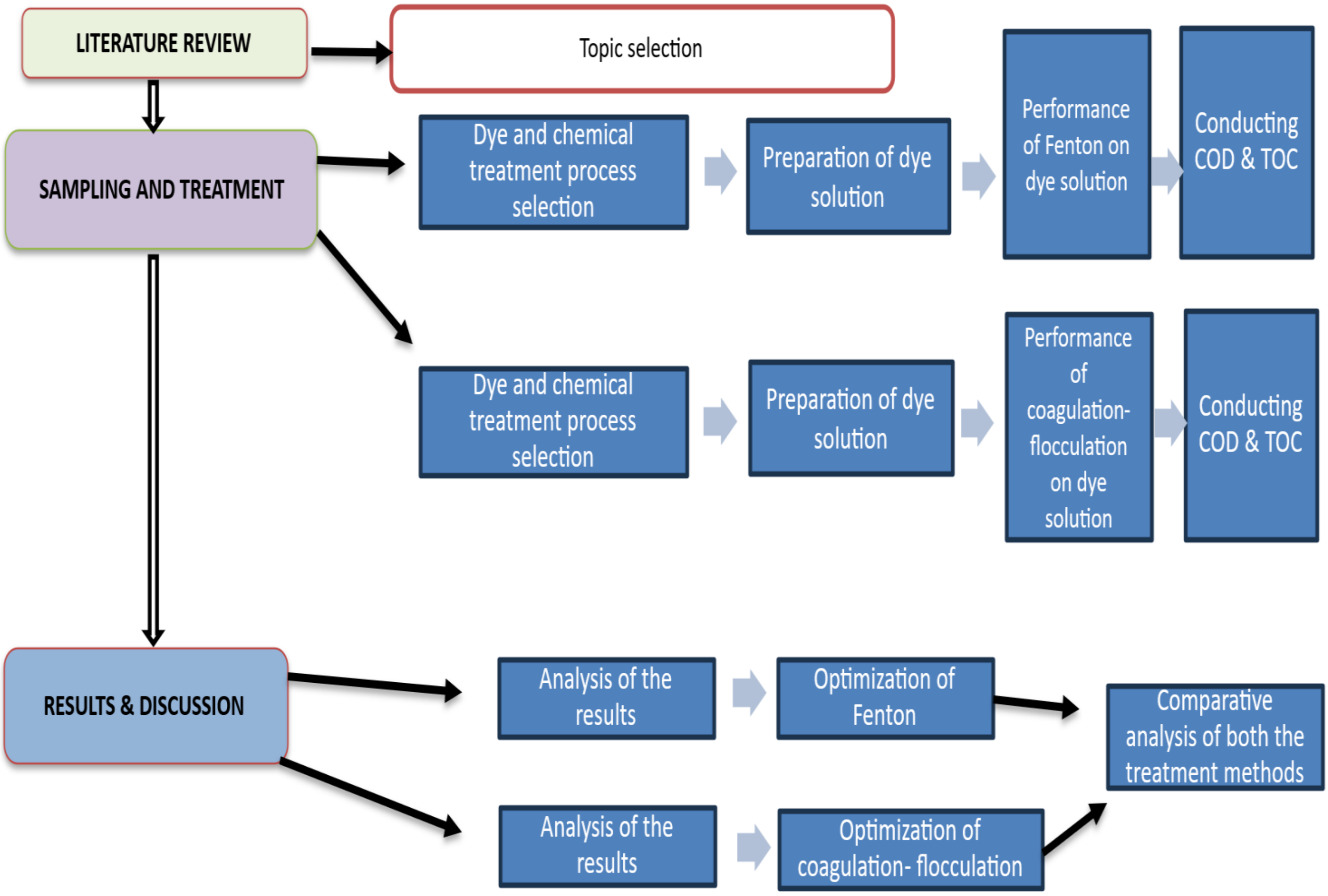
When biological systems fail, plant operators usually turn to two main chemical treatments: coagulation-flocculation and the Fenton process. Coagulation-flocculation essentially acts as a chemical net. By tweaking the water's pH and adding metal salts like ferric chloride or alum, the dissolved dye particles lose their charge, clump together into larger flocs, and sink to the bottom. It is fast, relatively simple, and brilliant at stripping color out of the water. The Fenton process takes a completely different route. It mixes iron with hydrogen peroxide to generate hydroxyl radicals—highly reactive chemical that tear apart the dye molecules at a molecular level rather than just sweeping them into sludge. The effectiveness of coagulation depends heavily on the type of dye; it easily handles insoluble disperse dyes but often struggles with highly soluble reactive dyes. The Fenton process can mineralize almost any organic compound, but. It only works efficiently in a highly acidic environment (around pH 3), requires careful handling of peroxide, and can leave behind residual iron that needs to be dealt with. While some studies argue that basic coagulation outperforms Fenton in overall efficiency, others suggest that the sludge produced by coagulation makes Fenton's molecular destruction the better long-term choice.

The Fenton process, recognized as one of the most effective Advanced Oxidation Processes (AOPs), is widely applied for the degradation of persistent organic pollutants in industrial wastewater. Its strength lies in the generation of highly reactive hydroxyl radicals (•OH) through the catalytic reaction between hydrogen peroxide (H_2O_2) and ferrous iron (Fe^{2+}) under acidic conditions. These non-selective radicals can oxidize a vast array of recalcitrant compounds, including synthetic dyes, phenolic derivatives, and pharmaceuticals, often achieving significant mineralization. Despite its high efficacy, the classical Fenton process has notable operational limitations. It requires strict acidic pH control (typically around pH 3) for optimal radical generation and to prevent iron precipitation. Furthermore, the process generates a substantial amount of iron hydroxide sludge as a byproduct when the pH is subsequently raised for effluent discharge, creating secondary waste and increasing handling costs nature. The high chemical oxygen demand (COD) often found in industrial effluents can also necessitate large, costly doses of H_2O_2. To mitigate these challenges and enhance overall treatment efficiency, the integration of Fenton oxidation with a subsequent coagulation stage using lime hydrate (calcium hydroxide, Ca $(OH)_2$) has emerged as a powerful coupled strategy. This sequential approach leverages the strengths of both unit processes. The primary Fenton step aggressively oxidizes and breaks down complex organic molecules. The secondary lime coagulation step then serves multiple critical functions: it neutralizes the acidic effluent, precipitates the dissolved iron catalyst (and other metals) as a settleable solid, and further removes residual organics, colour.

Coagulation-flocculation is a fundamental physio-chemical process in water and wastewater treatment, widely used for the removal of suspended solids, colloids, color, and organic matter. The process involves two sequential steps: coagulation, where destabilization of colloidal particles occurs through charge neutralization, followed by flocculation, where destabilized particles aggregate into larger, settleable flocs. The efficiency of this process hinges critically on the selection of appropriate coagulants and flocculants. In recent years, advanced polymeric and composite coagulants like Poly Aluminum Chloride (PAC), Polyacrylamide (PAM), and Poly aluminum Ferric Chloride (PAFC) have gained prominence due to their superior performance over conventional metal salts like alum or ferric chloride.

The core challenge in treating complex wastewaters, such as those from textile or dyeing industries, is the effective removal of both colloidal particulates and dissolved organic macromolecules. Traditional coagulants often require high doses, produce large volumes of sludge, and have a narrow effective pH range. This has driven the development of pre-polymerized coagulants like PAC and composite coagulants like PAFC, which offer higher charge neutralization capacity, wider pH applicability, and reduced sludge generation. When used in conjunction with high-molecular-weight organic polymers like PAM as a flocculant aid, these primary coagulants can form larger, denser, and more shear-resistant flocs, significantly enhancing settling rates and clarification efficiency.

2. METHODOLOGY:



- Dye and chemical process selection for experiments typically involves choosing azo dye or Reactive dye (bodal navy blue GB).
- Fenton process is selected as an advanced oxidation process (AOP) using ferrous sulfate ($FeSO_4 \cdot 7H_2O$) and hydrogen peroxide (H_2O_2) for hydroxyl radical generation.
- Coagulation-flocculation employs inorganic coagulants like Poly Aluminum Chloride (PAC) or Polyacrylamide (PAM)with Poly aluminum Ferric Chloride (PAFC).
- Preparation of dye solution is carried out by accurately weighing and dissolving a known quantity of dye powder (100 mg/L to mimic industrial concentrations) in distilled water under stirring for 30–60 minutes at room temperature until complete homogeneity is achieved.
- Performance of Fenton on dye solution is highly effective, achieving 90–99% decolorization and 60–85% COD/TOC removal within 30–60 minutes through hydroxyl radical. The process operates optimally at pH 2.5–3.5 but produces sludge as a byproduct, with efficiency governed by the Fe^{2+}/H_2O_2 ratio.
- Performance of coagulation-flocculation on dye solution demonstrates rapid color removal (85–98% within 10–60 minutes), it achieves only 30–60% COD/TOC reduction as it primarily removes particulate/colloidal matter, making it suitable mainly for decolorization and solids separation.

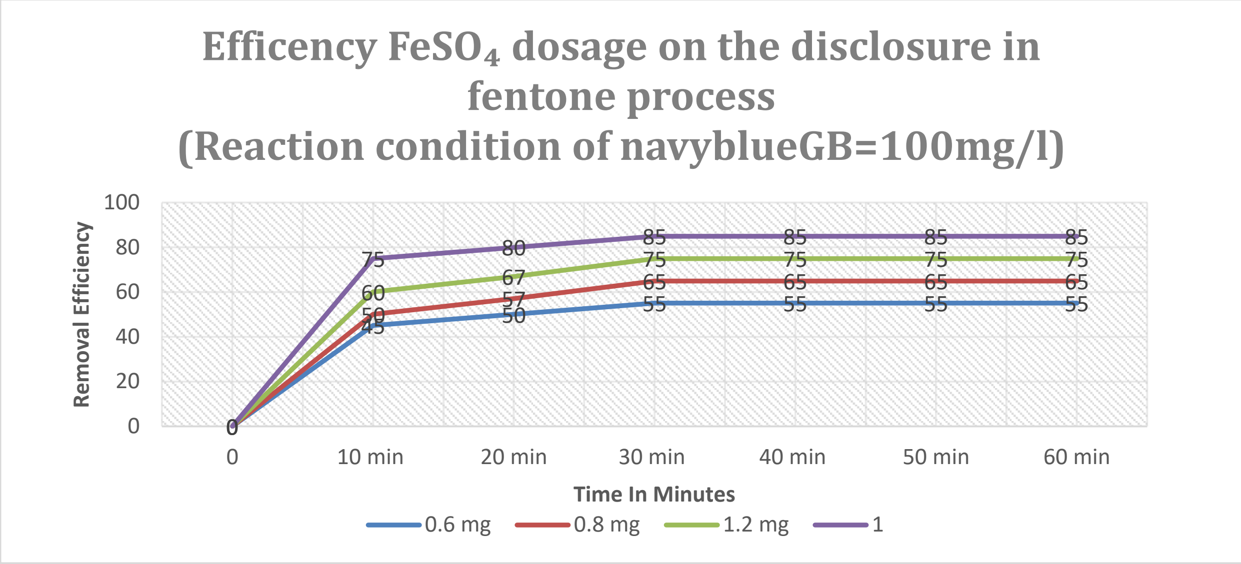
3. RESULT AND DISCUSSION:

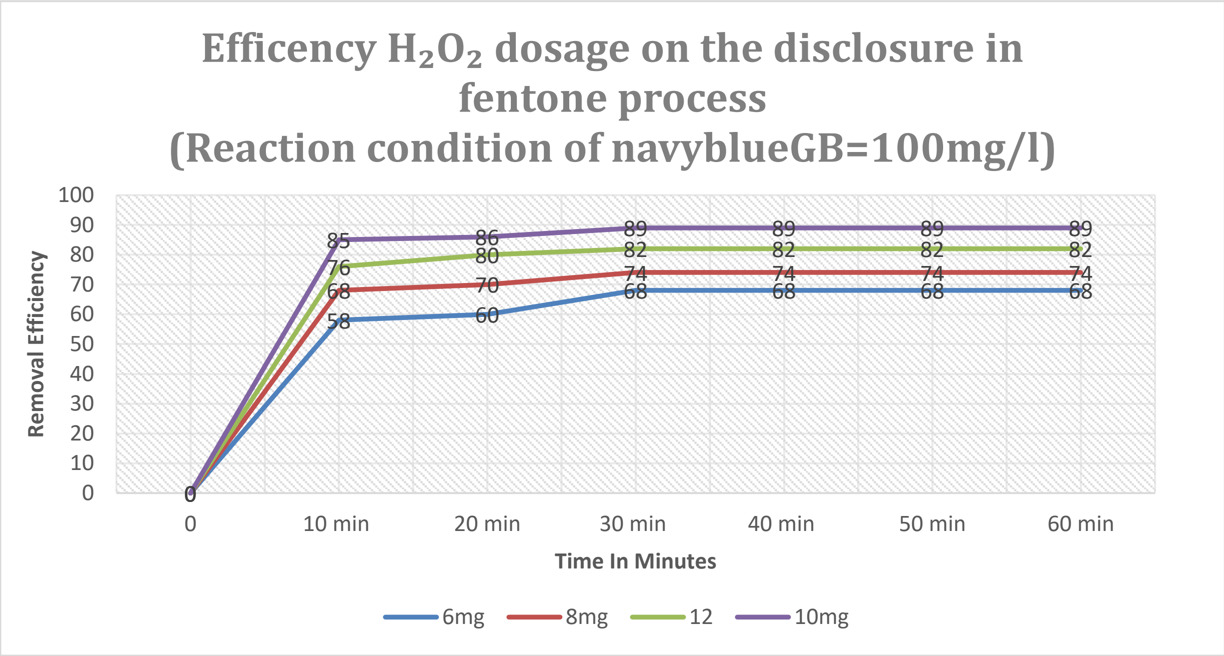
3.1 Optimization of Dosage of chemicals in Fenton Process.

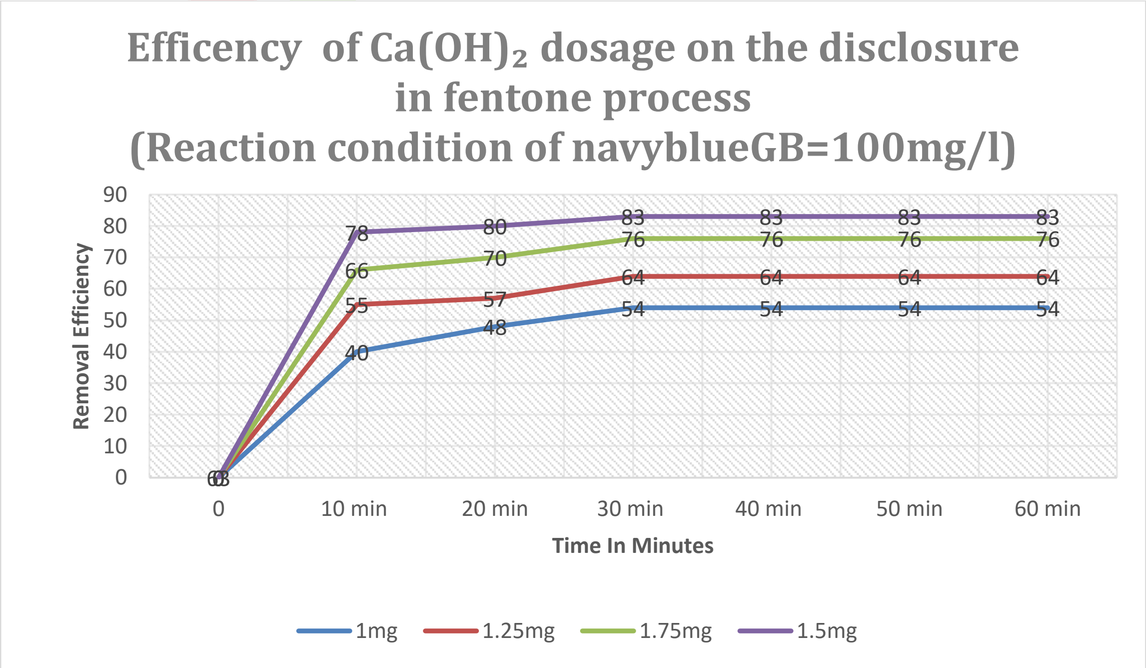
Optimization of Navy-blue GB dye solution
Chemical Dosages Used (per 125 mL sample)

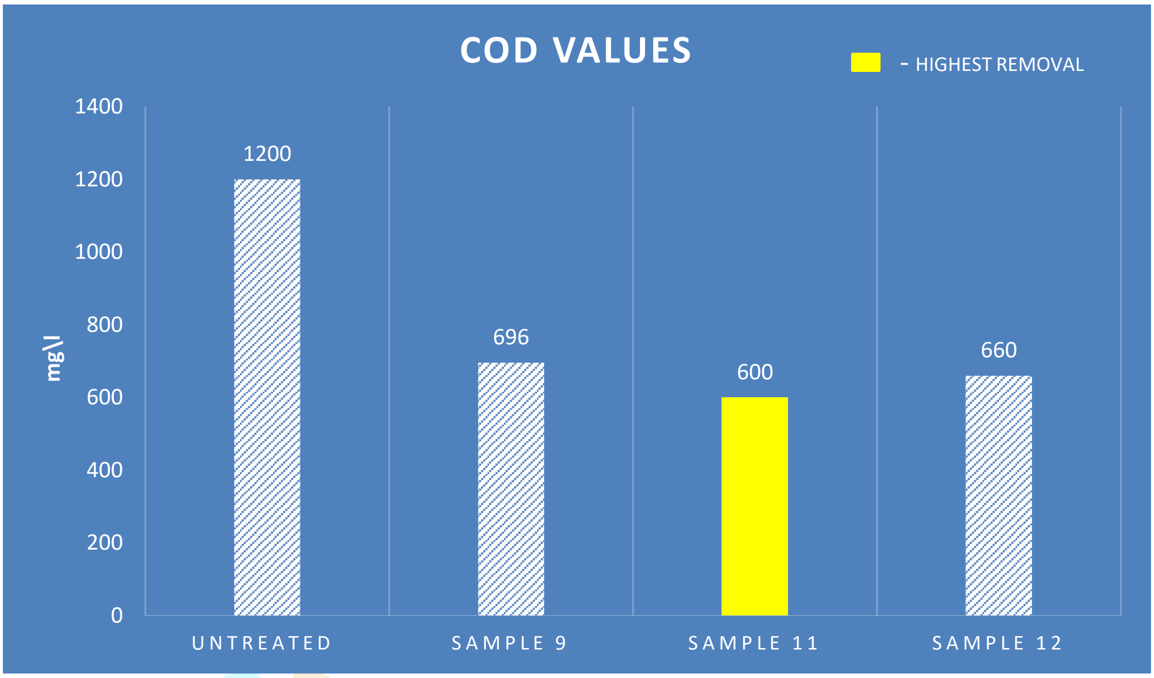
Sample No.	Ferrous Sulphate ($FeSO_4$)	Hydrogen Peroxide (H_2O_2)	Lime Hydrate ($Ca(OH)_2$)
1	0.6 mg	8 ml	1 mg
2	0.8 mg	8 ml	1 mg
3	1 mg	8 ml	1 mg
4	1.2 mg	8 ml	1 mg
5	1 mg	6 ml	1 mg
6	1 mg	8 ml	1 mg
7	1 mg	10 ml	1 mg
8	1 mg	12 ml	1 mg
9	1 mg	10 ml	1 mg
10	1 mg	10 ml	1.25 mg
11	1 mg	10 ml	1.5 mg
12	1 mg	10 ml	1.75 mg

Table No. 1

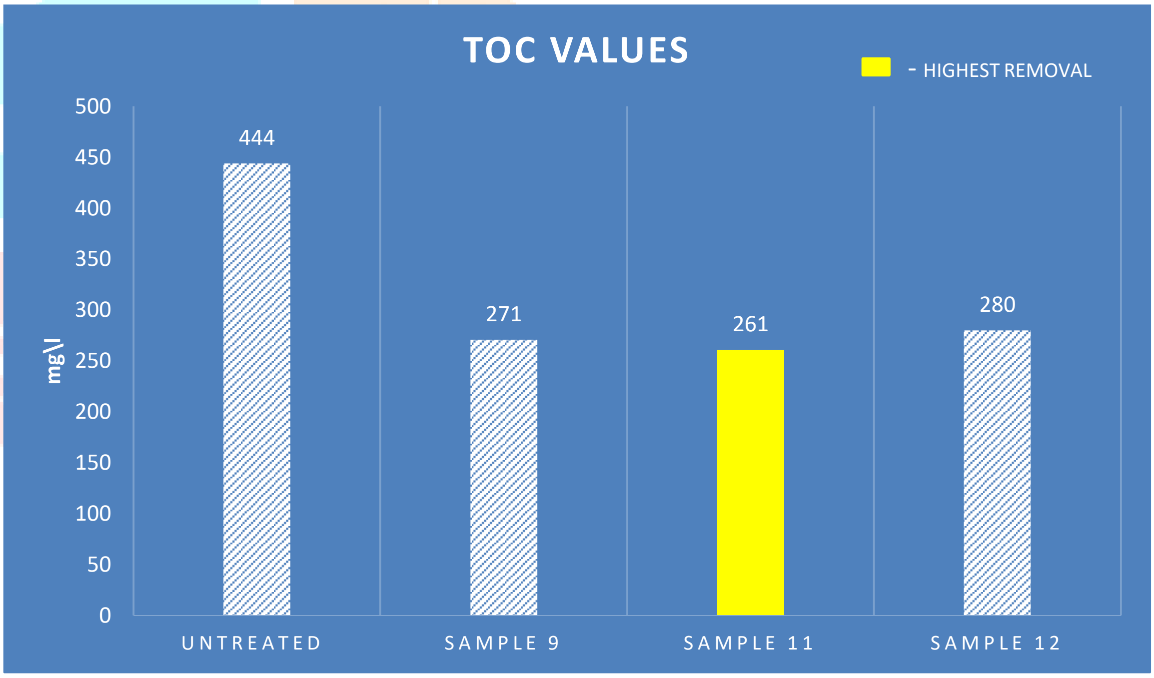

Efficency FeSO4 dosage on the disclosure in fentone process
(Reaction condition of navyblueGB=100mg/l)
Removal Efficiency
Time In Minutes
0
10 min
20 min
30 min
40 min
50 min
60 min
0.6 mg
0.8 mg
1.2 mg
1


Efficency H2O2 dosage on the disclosure in fentone process
(Reaction condition of navyblueGB=100mg/l)
Removal Efficiency
Time In Minutes
0
10 min
20 min
30 min
40 min
50 min
60 min
6mg
8mg
12
10mg


Efficency of Ca(OH)2 dosage on the disclosure in fentone process
(Reaction condition of navyblueGB=100mg/l)
Removal Efficiency
Time In Minutes
0
10 min
20 min
30 min
40 min
50 min
60 min
1mg
1.25mg
1.75mg
1.5mg



(Sample 11 achieved 50% removal efficiency)



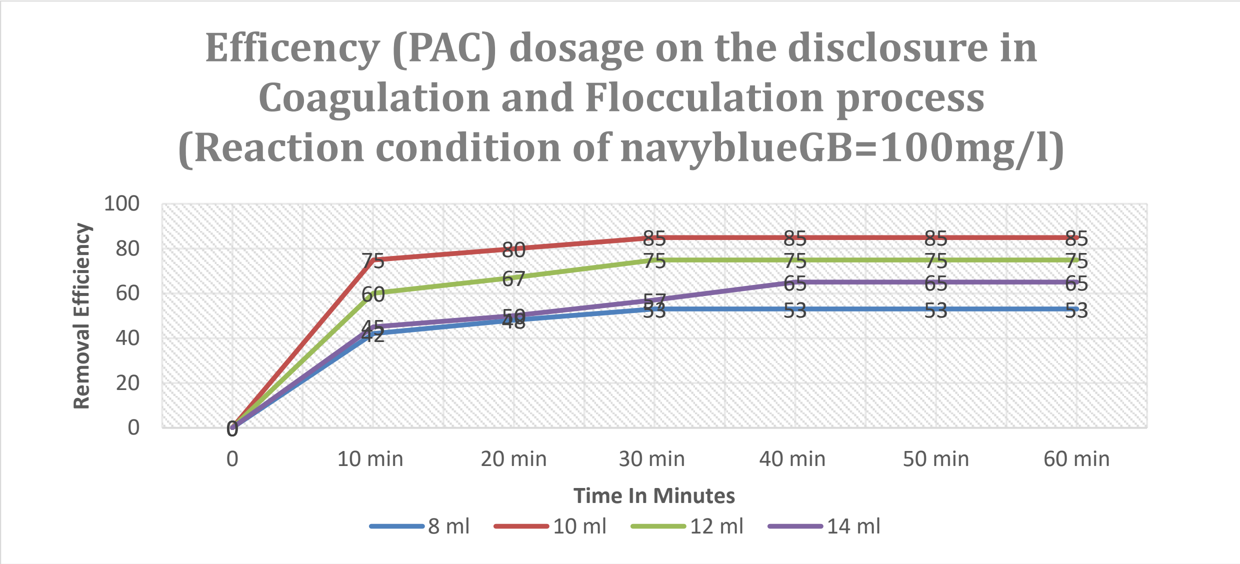
(Sample 11 achieved 41.2% removal rate)

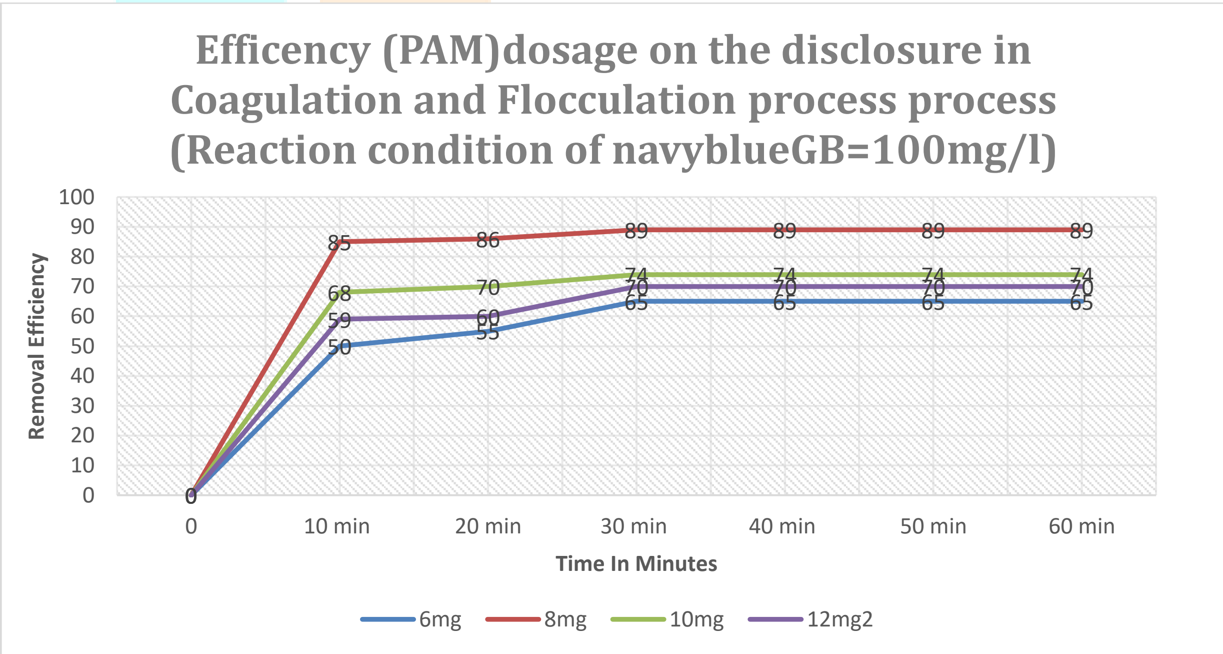
3.2 Optimization of Dosage of chemicals in Coagulation and Flocculation Process.

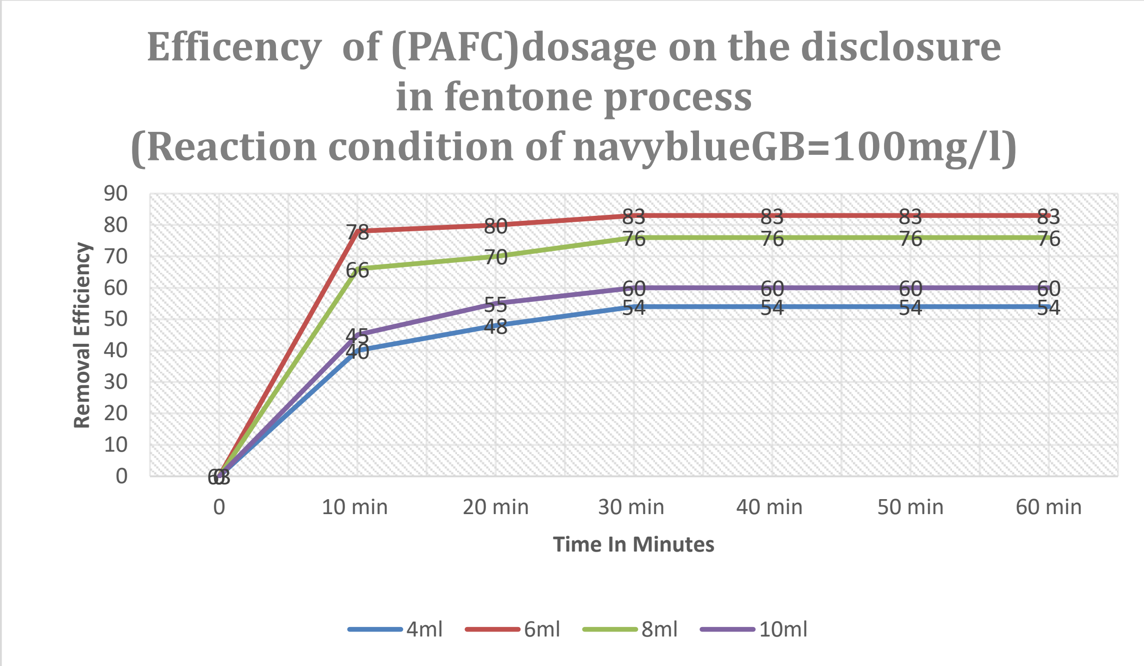
Optimization of Navy-blue GB dye solution
Chemical Dosages Used (per 125 mL sample)

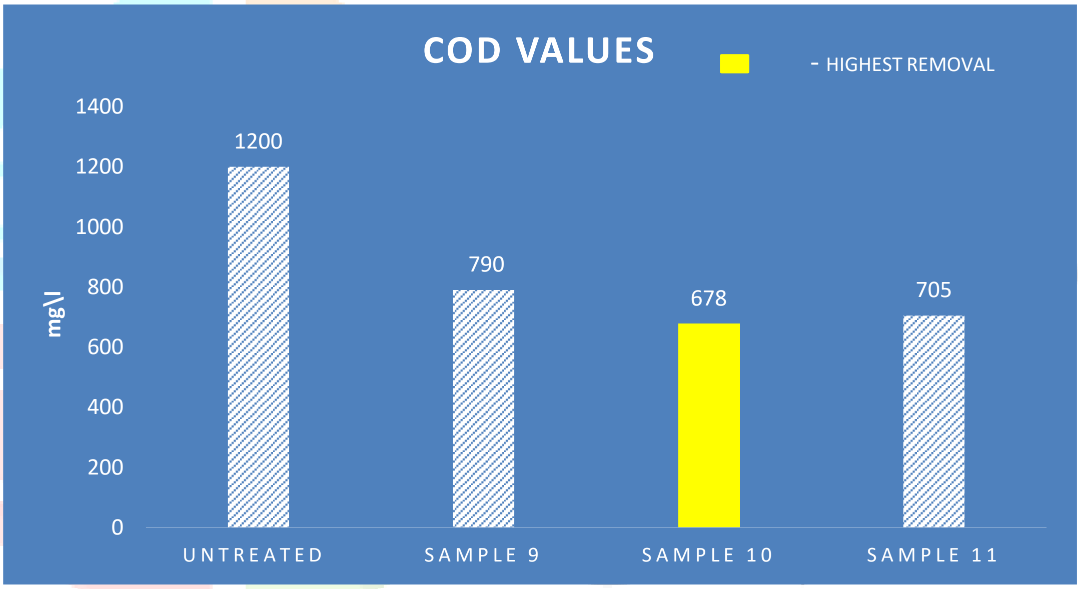
Sample No.	Poly Aluminum Chloride (PAC)	Polyacrylamide (PAM)	Poly aluminum Ferric Chloride (PAFC)
1	8 ml	6 ml	4 ml
2	10 ml	6 ml	4 ml
3	12 ml	6 ml	4 ml
4	14 ml	6 ml	4 ml
5	10 ml	6 ml	4 ml
6	10 ml	8 ml	4 ml
7	10 ml	10 ml	4 ml
8	10 ml	12 ml	4 ml
9	10 ml	8 ml	4 ml
10	10 ml	8 ml	6 ml
11	10 ml	8 ml	8 ml
12	10 ml	8 ml	10 ml

Table No. 2

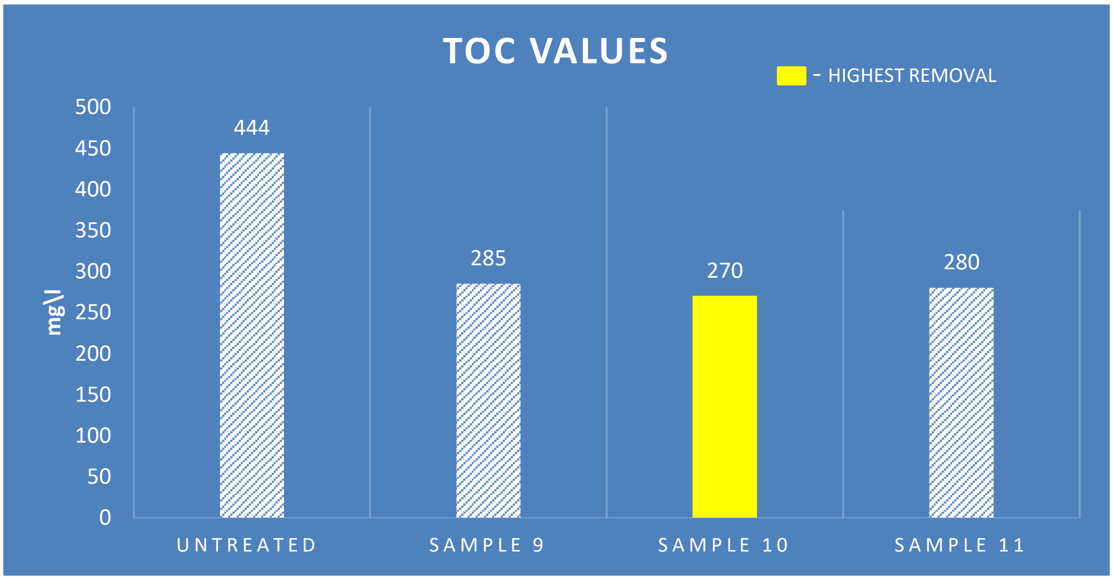

Efficency (PAC) dosage on the disclosure in Coagulation and Flocculation process (Reaction condition of navyblueGB=100mg/l)
Removal Efficiency
Time In Minutes
0
10 min
20 min
30 min
40 min
50 min
60 min
8 ml
10 ml
12 ml
14 ml


Efficency (PAM)dosage on the disclosure in Coagulation and Flocculation process process (Reaction condition of navyblueGB=100mg/l)
Removal Efficiency
Time In Minutes
0
10 min
20 min
30 min
40 min
50 min
60 min
6mg
8mg
10mg
12mg2





(Sample 10 achieved 43.5% highest removal efficiency)



(Sample 10 achieved 39.19% removal efficiency)

4. CONCLUSION

A. **For Fenton Process**
COD: - 50% removal rate with Sample no 11
TOC: - 41.2% removal rate with Sample no 11

B**. For Coagulation – Flocculation Process**
COD: - 43.5% removal rate with Sample no 10
TOC: - 39.19 % removal rate with Sample no 10

The Fenton Process demonstrated superior performance in treating the wastewater sample compared to the Coagulation-Flocculation Process.

Detailed Comparison:

- COD Removal Efficiency:
  The Fenton Process achieved a Chemical Oxygen Demand (COD) removal rate of 50% (Sample 11), which is higher than the 43.5% achieved by the Coagulation-Flocculation Process (Sample 10). This indicates that the Fenton Process is more effective at oxidizing the overall organic pollutants.

- TOC Removal Efficiency:
  Similarly, for Total Organic Carbon (TOC), the Fenton Process reached a removal rate of 41.2% (Sample 11), outperforming the Coagulation-Flocculation Process, which recorded a removal rate of 39.19% (Sample 10). The higher TOC removal suggests that the Fenton Process was slightly more effective at mineralizing organic carbon.

Final Remark:

Under the conditions tested (specifically referencing Sample 11 for Fenton and Sample 10 for Coagulation), the Fenton advanced oxidation process proved to be the more effective treatment method for reducing both the chemical oxygen demand and the total organic carbon content of the wastewater.

5. REFERENCES

[1] Khelassi-Sefaoui, A., et al. (2025). "Advances in Dye Degradation in Industrial Textile Effluent: Unveiling the Potential of Fenton, Photo-Fenton, and Helio-Photo-Fenton Processes for Environmental Conservation." Arabian Journal of Chemistry.

[2] Al-Tohamy, R., et al. (2022). "A Critical Review on the Sample of Dye-Containing Wastewater: Ecotoxicological and Health Concerns of Textile Dyes and Possible Remediation Approaches for Environmental Safety." Ecotoxicology and Environmental Safety, Vol. 231, 113160.

[3] Tripathi, M., et al. (2023). "Recent Strategies for the Remediation of Textile Dyes from Wastewater: A Systematic Review." Toxics, 11(11), 940. PMC: PMC10674586.

[4] Meurs, E., et al. (2024). "Study on Fenton-Based Discoloration of Reactive-Dyed Waste Cotton as a

Pre-Sample for Textile Recycling." Nature Scientific Reports, 14, 24367.

[5] Ledakowicz, S., & Pazdzior, K. (2021). "Recent Achievements in Dyes Removal Focused on Advanced Oxidation Processes Integrated with Biological Methods." Molecules, 26(4), 870. PMC: PMC7914684.

[6] Yadav, A., et al. (2013). "Removal of Chemical Oxygen Demand and Colour from Simulated Textile Wastewater Using a Combination of Chemical/Physicochemical Processes." Industrial & Engineering Chemistry Research, 52(30), 10063-10071.

[7] Ateş, A.E., et al. (2025). "Integrated Salt and Energy Recovery from Dyeing Wastewater via Fenton and Photo-Fenton Oxidation: Industrial Approach." Journal of Water Process Engineering.

[8] Chauhan, P.S., et al. (2024). "Combined Advanced Oxidation Dye-Wastewater Sample Plant Using Solar Energy: Design to Demonstration." npj Clean Water, 7(1), 27.

[9] Eslami, A., et al. (2013). "Decolorization and COD Removal from Real Textile Wastewater by Chemical and Electrochemical Fenton Processes." Journal of Environmental Health Science & Engineering, 11, 31. PMC: PMC3880033.

[10] Sanja Vasiljević (2023). “Efficiency of Coagulation/Flocculation for the Removal of Complex Mixture of Textile Fibers from Water”.