

DICYANDIAMIDE-FORMALDEHYDE (DCD-F) RESIN FOR POLLUTANTS REMOVAL FROM TEXTILE WASTEWATER

AIDA BAIZURA BAHARIM¹, RADIN MAYA SAPHIRA RADIN MOHAMED^{1,2,*}, AHMER ALI SIYAL¹, NORLIZA MISROM³, NUR DIYANA HAIRUDDIN¹, WAN AFNIZAN BIN WAN MOHAMED¹

¹Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, Malaysia

²Micropollutant Research Centre (MPRC), Institute for Integrated Engineering (I²E), Universiti Tun Hussein Onn, Batu Pahat, 86400, Malaysia

³Eco Solution Services Sdn Bhd, No 1 & 3, Jalan Emas Jaya 1, Taman Industri Emas Jaya, Tongkang Pechah, 83010, Batu Pahat, Johor, Malaysia

*Corresponding Author: maya@uthm.edu.my

Abstract

This study aims to evaluate the efficiency of dicyandiamide-formaldehyde (DCD-F) resin as a coagulant for treating textile wastewater. Studies on the use of DCD-F resin for textile wastewater treatment under optimal conditions are still lacking. Coagulation and flocculation experiments were conducted using a jar test to assess the removal of colour, chemical oxygen demand (COD), total suspended solids (TSS), and turbidity under varying conditions of pH (5.5 to 9.5), resin dosage (50 to 100 ppm), mixing speeds (rapid: 120 to 180 rpm, slow: 30 to 45 rpm), and retention times (60 to 180 minutes). For sample A, the study identified optimal removal efficiencies of 95.96% for colour, 52.05% for COD, 98.5% for TSS, and 99.28% for turbidity at a resin dosage of 100 ppm, a pH of 7, a rapid mixing speed of 150 rpm, and a retention time of 180 minutes. However, for sample B, which had significantly higher pollution levels with a COD concentration of 1315 mg/L and a colour value of 2444 ADMI, DCD-F resin alone was insufficient to achieve optimal treatment efficiency, indicating the need for additional coagulants or treatment steps. A cost-benefit analysis showed that treating textile wastewater with DCD-F resin at the optimal conditions for sample A is highly economical. costs RM 18 per month, making it more economical than aluminium sulphate and ferric chloride.

Keywords: Chemical oxygen demand, Decolouring agent, Textile wastewater, Total suspended solid, Turbidity.

1. Introduction

One of the largest industrial water consumers globally is textile wastewater, characterized by its high volume and complexity. It is estimated that 100 -200 L of water per kilogram is used in this industry due to the processing of textile products [1]. The textile wastewater has high chemical oxygen demand (COD), colour, total suspended solids (TSS), turbidity, pH, and biochemical oxygen demand (BOD). Previous studies reported that it contains a wide range of contaminants, including colour (352-3743 ADMI), COD (822-912 mg/L), TSS (31-113 mg/L), turbidity (37.4-54.8 NTU), and high pH (10.62-10.78) levels [2]. Globally, more than 700,000 tonnes of textile dyes are produced annually and approximately 100,000 tonnes are available commercially. It has been observed that around 10-15 % of the dyes are washed out and find their way into the textile wastewater [3]. These dyes dissolve in water and harm the environment. Therefore, textile wastewater must be treated prior to its discharge into the water sources.

Removal of colour, COD, TSS, and turbidity is a significant challenge in the textile industry due to the complex composition of wastewater. According to the Environmental Quality Act 1974, wastewater discharge must meet specific standards before being released into water resources. For Standard A, which applies to discharge into more sensitive areas such as upstream water sources, the maximum allowable colour limit is 100 ADMI, while for Standard B, applicable to less sensitive areas like downstream discharges, the limit is 200 ADMI. Additionally, the permissible COD levels are capped at 80 mg/L for Standard A and 250 mg/L for Standard B. TSS are also strictly regulated, with limits of 50 mg/L and 100 mg/L for Standards A and B, respectively. The pH range for Standard A discharge is between 6.0 to 9.0, whereas Standard B allows a slightly broader range of 5.5 to 9.0. These stringent limits emphasize the importance of effective treatment technologies to ensure compliance and minimize environmental impact.

Conventional approaches for textile wastewater treatment include biological, physical, chemical, and hybrid methods. However, these methods face significant limitations. Biological processes are often ineffective as dyes are resistant to biodegradation and toxic to microorganisms [4]. Physical methods, such as membrane separation, encounter fouling and high operational costs, while ion exchange demands expensive maintenance [5, 6]. Chemical oxidation, despite its efficiency, involves excessive chemical consumption and generates hazardous by-products [7]. Advanced processes like photocatalytic degradation, which utilize nanoparticles to degrade dyes under light exposure, have shown potential for effective dye removal [8-10]. However, its practical implementation is hindered by high costs, the need for specialized equipment, and challenges in recovering and reusing nanoparticles. In contrast, coagulation-flocculation emerges as a practical and cost-effective solution, capable of removing diverse contaminants efficiently. Its simplicity, cost efficiency, and adaptability make it the preferred choice for textile wastewater treatment [11].

Dicyandiamide-Formaldehyde (DCD-F) resin is an organic coagulant commonly employed in decolourization and coagulation processes for wastewater treatment. As a cationic polymer, DCD-F resin neutralizes the net negative charge of suspended particles in water, facilitating the aggregation of smaller particles into larger ones that settle more quickly through charge neutralization mechanisms. Previous study has demonstrated that DCD-F resin exhibits the highest colour removal efficacy, achieving 96.7% at an optimal pH of 8, further highlighting its potential as a reliable coagulant [12]. Despite its industrial applications, there

remains a lack of comprehensive optimization studies to evaluate the impact of various operational variables on the performance of DCD-F resin. Current studies primarily focus on colour and COD removal, leaving a critical gap in understanding its effectiveness for removing other contaminants such as TSS and turbidity.

This paper evaluates the performance of DCD-F resin in removing colour, COD, TSS, and turbidity under varying pH levels, coagulant dosages, mixing speeds, and retention times. Additionally, a cost-benefit analysis was conducted to evaluate its economic feasibility.

2. Materials and Methods

2.1. Sample collection

The textile wastewater samples were collected in sanitized and contaminant free containers from the Tongkang Pecah textile industry, Batu Pahat. The sample containers usage guidelines during sample collection are shown in Table 1 [13]. The methods and equipment used for determining characteristics of textile wastewater are shown in Table 2 [13].

Table 1. The method of preservation and sample container, Matrix: Wastewater and Container: Plastic [13].

Parameter	Min sample size	Preservative	Holding time
COD	100 ml	H ₂ SO ₄ to pH < 2, cool 6 C°	28 days
Colour	250 ml	Cool 6 C°	48 hours
TSS	500 ml	Cool 6 C°	7 days
Turbidity	250 ml	Cool 6 C°	48 hours

Table 2. The standard method of parameter and equipment used in the study [13].

Parameter	Method/Standard	Equipment
Colour	Standard Method APHA 2120 (Direct Reading)	DR 6000
COD	Standard Method APHA 5220-D (Direct Reading)	DR 6000
TSS	Standard Method APHA 2540-D	DR 6000
Turbidity	Standard Method APHA 2130	TN-100

2.2. Coagulation and flocculation of textile wastewater

The coagulation and flocculation of textile wastewater was conducted through jar test as shown in Fig. 1. The first step involved determining the optimal pH level by varying the pH from 5.5 to 9.5, using a rapid mixing speed of 150 rpm for 1 minute, followed by a slow mixing speed of 45 rpm for 15 minutes, with a retention time of 180 minutes. Subsequently, with the optimal pH established, the ideal dosage of DCD-F resin for effectively treating textile wastewater was determined. The optimal coagulant dose at the optimal pH was determined by adding varying coagulant doses, mixing speed, and retention time to textile. Each experiment was conducted in triplicates and an average value was reported.

2.2.1. Optimization of operating parameters of Dicyandiamide-Formaldehyde (DCD-F) Resin

The values of independent factors pH (X1), DCD-F resin dosage (X2), hydraulic retention time (X3), and mixing speed (X4) for the sample are shown in Table 3.

The dependent variables include removal rate based on the removal of colour (y1), COD (y2), TSS (y3) and turbidity (y4).

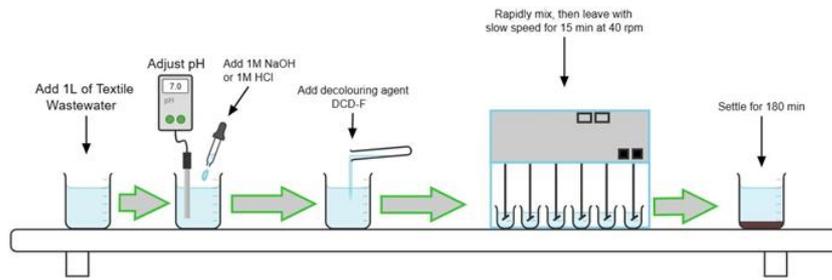


Fig. 1. Diagram of the jar test arrangement for optimisation of DCD-F resin to remove colour, COD, TSS and turbidity in textile wastewater.

Table 3. Independent factor for the sample.

Factor	DCD-F resin dosage (ppm)	Value of pH	Mixing speed -rapid/slow (rpm)	Hydraulic retention time (minutes)	Reference
Symbol	X1	X2	X3	X4	
	40 - 140	5.5 - 9.5	120-180/45	60-180	Karyab et al. [12]; Gao et al. [14]

2.3. Determination of pH

The pH of textile wastewater during coagulation and flocculation was determined using pH meter (pH hq440d). Each sample's pH was changed. After the completion of the jar test, the sample was mixed at a slow speed (45 rpm) for a few minutes before the pH value was determined.

2.4. Determination of colour

To ensure the validity and accuracy of the calculations, the results are compared to typical projectile configurations (as shown in Figs. 2 and 3) are selected for this purpose. The specifications of the models and test conditions are shown in Table 1.

2.5. Determination of chemical oxygen demand (COD)

High-range COD by the reactor digestion method was used to determine the COD of textile wastewater using the prepared digestion solution by HACH for COD 20-1500 mg/L. COD was determined using DR6000. However, all of that conducted after preparing the sample of COD combination in DRB 200, which had two independently controllable enabled settings that were 150 °C temperature for 120 min [15].

2.6. Determination of total suspended solid (TSS)

TSS of textile wastewater was determined using a HACH DR6000 spectrophotometer. The removal efficiency of DCD-F resin was determined using Eq. (1).

$$\text{Removal Efficiency (\%)} = \frac{(C_i - C_f)}{C_i} \times 100 \quad (1)$$

where C_i is the initial concentration of a sample and C_f is the final concentration of a sample [16].

2.7. Determination of turbidity

A Eutech turbidity meter (TN-100) was used to determine the turbidity of textile wastewater samples before and after treatment. To measure turbidity, the supplied sample bottle of the TN-100 was filled with the sample until it reached the 10 ml line, and then, the bottle was placed at the TN-100 and the turbidity was measured.

2.8. Cost-benefit analysis using excel

Microsoft Excel was used to determine the cost-benefit analysis of DCD-F resin. Market pricing for DCD-F resin, Aluminium Sulphate, and ferric chloride are RM6/kg, RM7.80/kg and RM13.80/kg, respectively. Eq. (2) was used to determine the optimum dosage of DCD-F resin for treating textile effluent.

$$\text{Treatment cost per month (RM)} = \text{Dosage cost per month} \times \text{Price} \left(\frac{\text{RM}}{\text{kg}} \right) \quad (2)$$

where, Flowrate = 1m³/day, Operating hours = 12 hours, Operating days = 30 days.

3. Results and Discussion

3.2. Characteristics of untreated textile wastewater

As shown in Table 4, the untreated samples exhibited significantly higher values for all parameters than the allowable limits outlined in the Environmental Quality Act 1974 (Standards A and B). The COD and TSS values for both samples exceeded the Malaysian sewage and industrial effluent discharge standards. Specifically, for sample A, COD was 292 mg/L compared to the standard limit of 80 mg/L, and TSS was 69 mg/L against the standard limit of 50 mg/L. For sample B, the COD value was 1315 mg/L, exceeding the standard limit of 250 mg/L, while TSS was 21 mg/L compared to the 100 mg/L limit.

The colour concentrations of both samples were also significantly higher than the standards. Using APHA 2017, method 2120B, sample A recorded 940 ADMI, exceeding the standard limit of 100 ADMI, while sample B showed 2444 ADMI, far above the standard limit of 200 ADMI. These results indicate that the raw water samples were highly polluted, particularly sample B. However, the pH values of sample A (9.0) and sample B (6.8) were within the acceptable ranges of 6.0–9.0 and 5.5–9.0, respectively. Turbidity values were not compared due to the absence of specific regulatory standards.

Table 4. Comparison of characteristics of untreated textile wastewater sample with Malaysian sewage and industrial effluent discharge standards.

Parameter	Unit	Concentration		Textile wastewater standard (Environmental Quality Act, 1974)	
		Sample A	Sample B	Standard A	Standard B
Colour (y1)	ADMI	940	2444	100	200
COD (y2)	mg/L	292	1315	80	250
TSS (y3)	mg/L	69	21	50	100
Turbidity (y4)	NTU	59.52	10.61	NA	NA

3.2. Effect of pH on the turbidity of textile wastewater

The graph in Fig. 2 indicated that determining the optimal pH for sample B was challenging due to its high concentrations of COD and colour, indicating more significant pollution compared to sample A. The turbidity remaining values for sample B showed minimal variation across the pH range, making it difficult to identify a definitive optimum pH for treatment. This suggests that using DCD-F resin alone as a coagulant is insufficient for treating highly polluted samples like sample B, as it may require additional coagulants or treatment steps.

In contrast, with lower pollution levels, sample A exhibited an optimal pH of 7, reducing turbidity to 1.32 NTU. This demonstrates that DCD-F resin alone is effective for treating less polluted textile wastewater, making sample A the focus of this review paper.

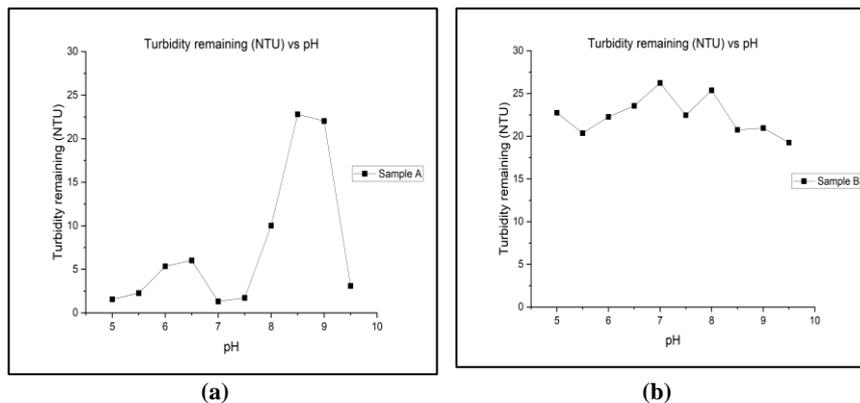


Fig. 2. (a) Optimization of pH in textile wastewater treatment for sample A (b) Optimization of pH in textile wastewater treatment for sample B.

3.3. Effect of dosage of DCD-F resin on colour removal

As shown in Fig. 3., in Set I, with a rapid mixing speed of 150 rpm, a slow mixing speed of 45 rpm, and a retention time of 180 minutes, the resin demonstrated significant efficacy, achieving colour removal percentages exceeding 95% at a dosage of 100 ppm. The observed results are consistent with Karyab et al. [12], where DCD-F resin achieved a maximum removal efficiency of 95.93% under similar conditions.

Sets II and III, with shorter retention times and different mixing speeds, demonstrated slightly lower efficiencies. Set II, characterized by a rapid mixing speed of 180 rpm, a slower mixing speed of 30 rpm, and a shorter retention time of 60 minutes. Whereas, Set III employed a rapid mixing speed of 120 rpm, a slow mixing speed of 40 rpm, and a retention time of 120 minutes. This aligns with prior research suggesting that sufficient contact time is critical for coagulants to achieve maximum efficacy [17].

All three sets successfully reduced colour concentrations below the Malaysian Environmental Quality Act (1974) limits of 200 ADMI (Standard B), even at dosages as low as 80 ppm. However, the diminishing returns observed beyond 100 ppm align with Nijagala and Vallameti [17], who cautioned that excess coagulant could lead to inefficiencies and increased treated water colour.

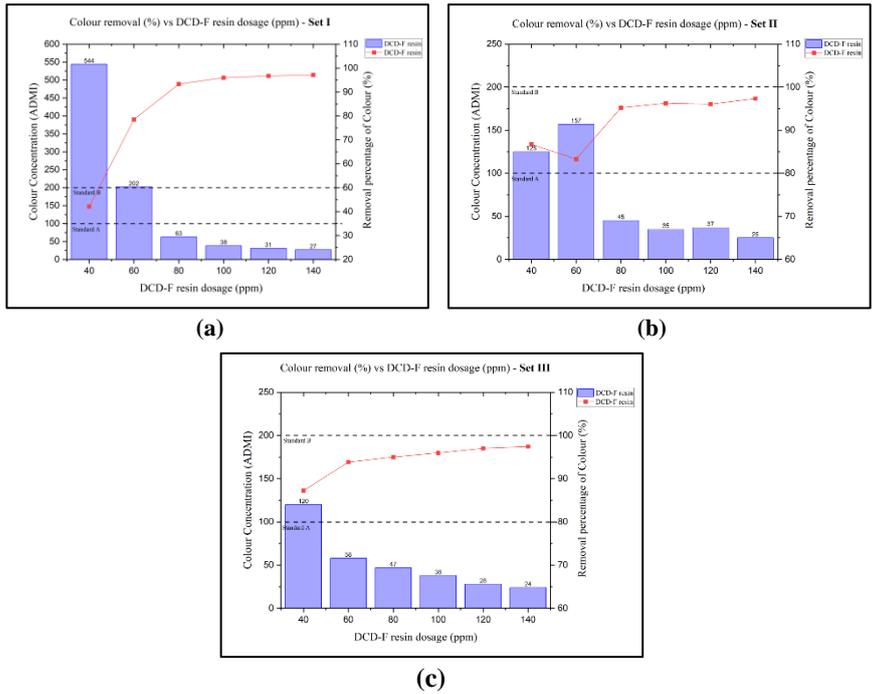


Fig. 3. Colour removal efficiency of DCD-F resin at different dosages for (a) Set I (b) Set II (c) Set III.

3.4. Effect of dosage of DCD-F resin on the removal of COD

In Set I, where the longest retention time of 180 minutes was applied with moderate mixing speeds, the highest COD removal efficiency was achieved at 140 ppm, reducing COD to 140 mg/L (Fig. 4). While this met Standard B (250 mg/L) of the Malaysian Environmental Quality Act (1974), it fell short of the stricter Standard A (80 mg/L). This finding aligns with prior studies emphasizing that prolonged retention times allow better pollutant-resin interaction, enhancing adsorption [18].

In Set II, the shorter retention time of 60 minutes and altered mixing conditions led to reduced removal efficiency, with COD concentrations ranging from 179–266 mg/L. The most effective removal rate was observed at a concentration of 80 ppm; however, the limited contact time may have restricted the resin’s adsorption capacity. Similarly, Set III, with a retention time of 120 minutes and moderate mixing speeds, showed slightly better COD removal than Set II but was still less effective than Set I. These results are consistent with previous research suggesting that both retention time and controlled mixing speed play critical roles in resin performance [19].

3.5. Effect of dosage of DCD-F resin on the removal of TSS

In Set I (Fig. 5), which utilized the longest retention time of 180 minutes and moderate mixing speeds, TSS concentrations decreased significantly at lower resin dosages, with the highest removal efficiency achieved at 80 ppm, reducing TSS to 5 mg/L. This result surpassed both Standard A (50 mg/L) and Standard B (100 mg/L) outlined in the Malaysian Environmental Quality Act (1974).

These findings align with the study by Yakameran and Aygun [19], which reported that longer retention times allow sufficient interaction between resins and suspended solids, leading to enhanced adsorption and sedimentation [20].

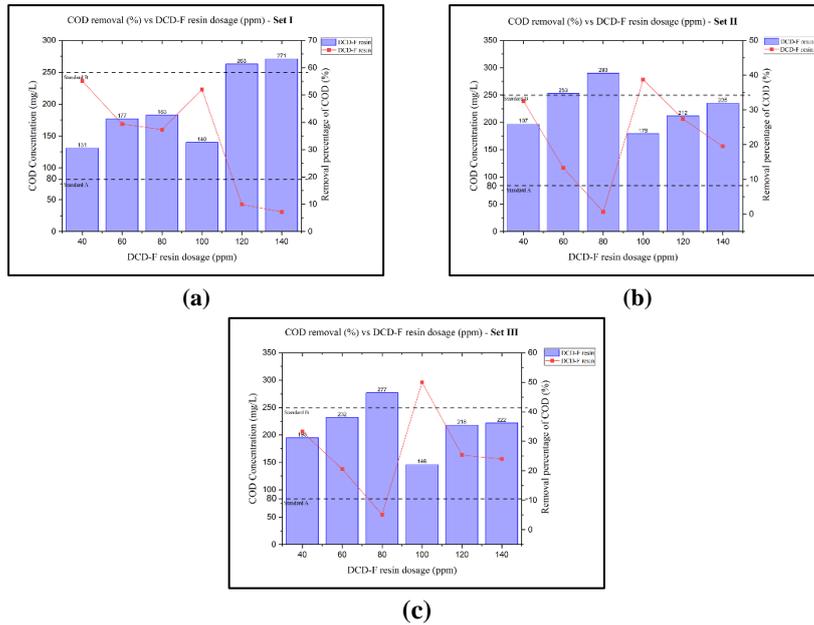


Fig. 4. COD removal efficiency of DCD-F resin at different dosages for (a) Set I (b) Set II (c) Set III.

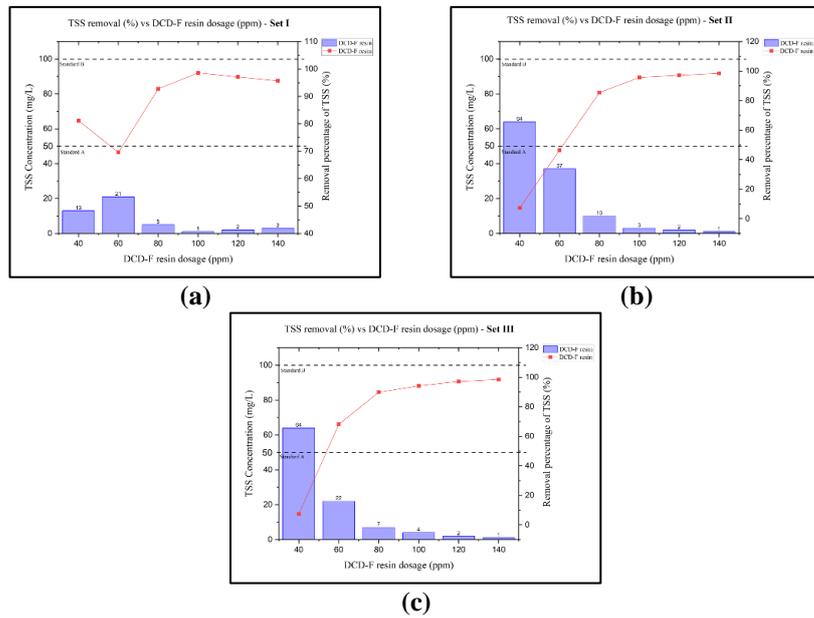


Fig. 5. TSS removal efficiency of DCD-F resin at different dosages for (a) Set I (b) Set II (c) Set III.

In Set II, the shorter retention time of 60 minutes and higher mixing speeds led to less effective TSS removal, achieving a minimum concentration of 19 mg/L at 80 ppm. While this result met Standard A, the reduced retention time and high rapid mixing likely limited the resin's ability to adsorb suspended particles effectively. The results are consistent with the findings of Li et al. [21], who highlighted that excessive mixing might disrupt flocculation processes and reduce the efficiency of suspended solid removal. Set III, with a retention time of 120 minutes and moderate mixing speeds, achieved a TSS concentration of 7 mg/L at 80 ppm, comparable to Set I. This result supports the conclusion by Naghan et al. [22], which noted that moderate mixing and sufficient retention time facilitate better floc formation and sedimentation.

3.6. Effect of dosage of DCD-F resin on the turbidity removal from textile wastewater

In Set I (Fig. 6), with a retention time of 180 minutes, turbidity dropped to 0.42 NTU at 80 ppm, achieving over 97% removal efficiency. Set II, with a shorter retention time of 60 minutes, showed slightly reduced efficiency, reaching 2.29 NTU at the same dosage. Set III, with 120 minutes of retention, achieved 1.32 NTU, demonstrating the importance of balancing mixing intensity and retention time for optimal performance. These findings align with studies highlighting the role of resin systems in turbidity reduction through adsorption and flocculation. Although no turbidity standard exists under Malaysia's Environmental Quality Act (1974), the results indicate that DCD-F resin is highly effective in meeting stringent water quality needs.

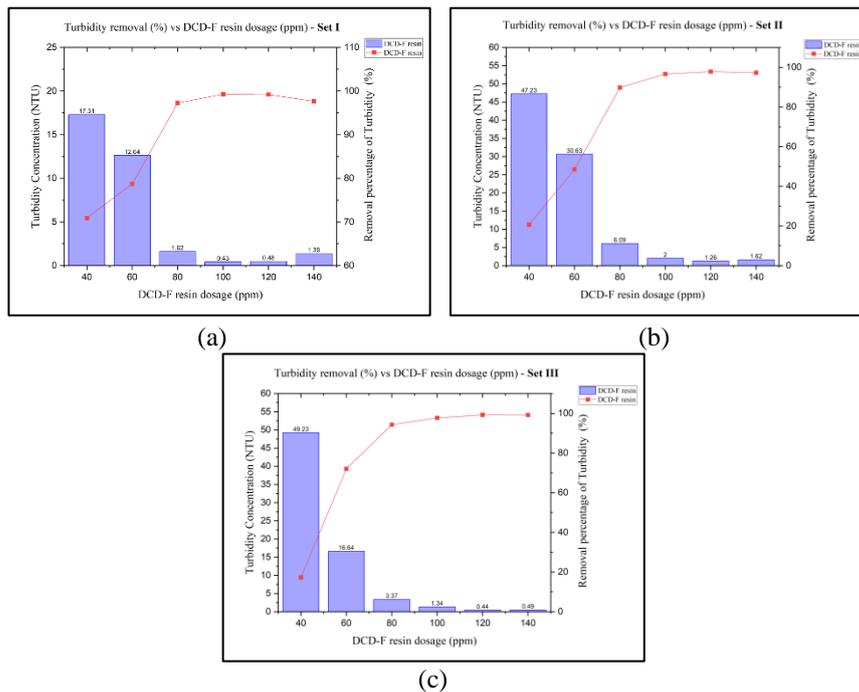


Fig. 6. Turbidity removal efficiency of DCD-F resin at different dosages for (a) Set I (b) Set II (c) Set III.

3.7. Cost-benefit analysis for optimal dosage of DCD-F resin

The optimum dosage of DCD-F resin for the sample was 100 ppm which removed 95.96% of colour, 52.05% of COD, 98.55% of TSS, and 99.28% of turbidity at a mixing speed of 150 rpm (rapid) and 45 (slow), and retention time of 180 minutes. The optimal value of DCD-F resin was used in a cost-benefit analysis. The monthly cost of treating this textile effluent is shown in Table 5.

The cost-benefit analysis was also determined for aluminium sulphate and ferric chloride coagulants by using their optimum dosages from the previous studies. An aluminium sulphate dosage of 500 ppm was used to remove 68.8% of colour, 36.19% of COD, and 19% of TSS [22]. The optimum dosage of ferric chloride of 2720 ppm was used to remove 91.89%, 85.40%, 98.66%, and 98.36% for colour, COD, TSS, and turbidity, respectively [23].

An optimal dosage of DCD-F resin of 100 ppm is able to successfully remove colour, COD, TSS, and turbidity from textile wastewater at a relatively low cost of RM 18.00 per month as compared to the removal of colour, COD, TSS, and turbidity at optimum dosages of aluminium sulphate and ferric chloride at the cost of RM 117.00 and RM 1126.08 per month.

Table 5. Cost-benefit analysis for optimal dosage of dicyandiamide-formaldehyde resin, aluminium sulphate and ferric chloride.

Chemical	Dicyandiamide-formaldehyde (DCD-F) resin	Aluminium sulphate	Ferric chloride
Price (RM/kg)	6	7.8	13.8
Jar test (PPM)	100	500	2720
Dosage per hour (kg)	0.008333	0.041667	0.226667
Dosage per day (kg)	0.1	0.5	2.72
Dosage per month (kg)	3	15	81.6
Treatment cost per day (RM)	0.6	3.9	37.54
Treatment cost per month (RM)	18	117	1126.08
Total cost (1m3)	RM 18	RM117	RM1126.08

4. Conclusion

In conclusion, at optimal conditions - pH 7, rapid mixing at 150 rpm, gradual mixing at 45 rpm, and a retention time of 180 minutes - the DCD-F resin effectively removed 95.96% of colour, 52.05% of COD, 98.55% of TSS, and 99.28% of turbidity from textile wastewater. The study highlighted that retention time significantly impacted COD removal, while mixing speed had minimal influence. Moreover, using DCD-F resin at an optimal dosage of 100 ppm was highly cost-effective, with a monthly treatment cost of RM 18, making it a more economical alternative to traditional coagulants like aluminium sulphate and ferric chloride.

Acknowledgement

This research was supported by Universiti Tun Hussein Onn Malaysia through TIER 1 grant (vot Q479) and GPPS grant (Vot Q567).

References

1. Jahan, N. et al. (2022). A comprehensive review on the sustainable treatment of textile wastewater: Zero liquid discharge and resource recovery perspectives. *Sustainability*, 14(22), 15398.
2. Daud, N.M.; Abdullah, S.R.S.; Hasan, H.A.; Othman, A.R.; and Ismail, N.I. (2023). Coagulation-flocculation treatment for batik effluent as a baseline study for the upcoming application of green coagulants/flocculants towards sustainable batik industry. *Heliyon*, 9(6), e17284.
3. Sharma, J.; Sharma, S.; and Soni, V. (2021). Classification and impact of synthetic textile dyes on Aquatic Flora: A review. *Regional Studies in Marine Science*, 45, 101802.
4. Al-Jaberi, F.Y.; Hadi, D.R.; and Ajjam, S.K. (2023). Electrocoagulation treatment of textile wastewater: A review. *Proceedings of 2nd Muthanna International Conference on Engineering Science and Technology*, Samawah, 2806(1).
5. Yasmeen, M.; Nawaz, M.S.; Khan, S.J.; Ghaffour, N.; and Khan, M.Z. (2023). Recovering and reuse of textile dyes from dyebath effluent using surfactant driven forward osmosis to achieve zero hazardous chemical discharge. *Water Research*, 230, 119524.
6. Guida, S.; Rubertelli, G.; Jefferson, B.; and Soares, A. (2021). Demonstration of ion exchange technology for phosphorus removal and recovery from municipal wastewater. *Chemical Engineering Journal*, 420, 129913.
7. Tanveer, R. et al. (2022). Comparison of ozonation, Fenton, and photo-Fenton processes for the treatment of textile dye-bath effluents integrated with electrocoagulation. *Journal of Water Process Engineering*, 46, 102547.
8. Kang, X. et al. (2020). Ultrafine copper nanoparticles anchored on reduced graphene oxide present excellent catalytic performance toward 4-nitrophenol reduction. *Journal of Colloid and Interface Science*, 566, 265-270.
9. Handojo, L.; Pramudita, D.; Mangindaan, D.; Indarto, A. (2020). *Application of Nanoparticles in Environmental Cleanup: Production, Potential Risks and Solutions*. In Bharagava, R. (Eds.), *Emerging Eco-friendly Green Technologies for Wastewater Treatment*. Springer, 45-76.
10. Samuel, M.S.; Jose, S.; Selvarajan, E.; Mathimani, T.; and Pugazhendhi, A. (2020). Biosynthesized silver nanoparticles using *Bacillus amyloliquefaciens*; Application for cytotoxicity effect on A549 cell line and photocatalytic degradation of p-nitrophenol. *Journal of Photochemistry and Photobiology B: Biology*, 202, 111642.
11. Badawi, A.K.; and Zaher, K. (2021). Hybrid treatment system for real textile wastewater remediation based on coagulation/flocculation, adsorption and filtration processes: Performance and economic evaluation. *Journal of Water Process Engineering*, 40, 101963.
12. Karyab, H.; Hamidi, Z.; Ghotbinia, F.; Khani, Z.M.; and Nazeri, N. (2023). Application of the central composite design and response surface methodology for optimization of reactive color removal from aqueous solutions using dicyandiamide-formaldehyde resin modified by ammonium chloride. *Desalination and Water Treatment*, 308, 217-228.

13. American Public Health Association. (2017). *Standard methods for the examination of water and wastewater*.
14. Gao, L.; Lv, X.; Zhang, C.; Song, H.; and Gao, X. (2021). Removal of color from simulated textile wastewater by a modified dicyandiamide-formaldehyde polymeric flocculant. *Desalination and Water Treatment*, 234, 227-233.
15. Kumar, J.E.; Mulai, T.; Kharmawphlang, W.; Sharan, R.N.; and Sahoo, M.K. (2023). The efficiency of Fenton, Fenton/MW and UV/oxidant processes in the treatment of a mixture of higher concentrations of azo dyes. *Chemical Engineering Journal Advances*, 15, 100515.
16. Boughou, N.; Majdy, I.; Cherkaoui, E.; Khamar, M.; and Nounah, A. (2018). Effect of pH and time on the treatment by coagulation from slaughterhouse of the city of Rabat. *Proceedings of 2nd International Congress on Materials and Structural Stability (CMSS-2017)*, Rabat, Morocco, 149, 02091.
17. Nijagala, M.; and Vallameti, U.K. (2024). Application of preformed Floc adsorbents in the removal of Acid Dye from an aqueous solution. *Chemical Engineering & Technology*, 47(3), 605-609.
18. Hamri, S. et al. (2022). Cleaning of wastewater using crosslinked poly(Acrylamide-co-Acrylic Acid) hydrogels: Analysis of rotatable bonds, binding energy and hydrogen bonding. *Gels*, 8(3), 156.
19. Yakameran, E.; and Aygun, A. (2021). Fate and removal of pentachlorophenol and diethylhexyl phthalate from textile industry wastewater by sequencing batch biofilm reactor: Effects of hydraulic and solid retention times. *Journal of Environmental Chemical Engineering*, 9(4), 105436.
20. Al-Tohamy, R. et al. (2022). A critical review on the treatment of dye-containing wastewater: Ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety. *Ecotoxicology and Environmental Safety*, 231, 113160.
21. Li, Y.; Xu, L.; Shi, T.; and Yu, W. (2021). The influence of various additives on coagulation process at different dosing point: From a perspective of structure properties. *Journal of Environmental Sciences*, 101, 168-176.
22. Naghan, D.J. et al. (2015). Efficiency comparison of alum and ferric chloride coagulants in removal of dye and organic material from industrial wastewater- a case study. *Bulgarian Chemical Communications*, 47(D), 206-210.
23. Abbas, M.J.; Mohamed, R.M.S.R.; Al-Sahari, M.; Al-Gheethi, A.; and Daud, A.M.M. (2021). Optimizing $FeCl_3$ in coagulation-flocculation treatment of dye wastes. *Songklanakarin Journal of Science and Technology*, 43(4), 1094-1102.