Removal of Color from Textile Dyeing Effluents Using Coagulation-Flocculation Process Coupled with Adsorption on Nanoparticles Process

Md Abu Sayed and Md Golam Mostafa*

Water Research Lab, Institute of Environmental Science, University of Rajshahi, Rajshahi 6205, Bangladesh

Abstract

Textile dyeing industries discharge large volumes of effluents that threaten sustainable water resources and environmental management. This study aimed to explore the feasibility of treating discharge textile dye effluents by combining coagulation and adsorption processes to achieve the required discharge wastewater standards. The X-RD analysis results confirmed that the synthesized iron-oxide particles were found to be within the nano-size range (10-20 µm). The chemical coagulation process showed about 75% color removal efficiency, and the cumulative color removal efficiency achieved was 99.5% in combined coagulation, followed by the adsorption process with iron-oxide nanoparticle adsorbents (IONPs). The SEM images showed the rough and porous surface of virgin IONPs, having a slightly hazy and smooth surface for the adsorbed IONPs. The EDX analysis confirmed the presence of various metal ions on the IONPs surface. The study illustrated that the combination of coagulation-flocculation (C-F) and adsorption onto IONPs was more efficient for decolorizing textile dyeing effluents than the single coagulation process. The study observed that the coagulant $FeSO_4$ and the adsorbent IONPs have the potential to treat textile dyeing effluents and achieve the required standards for discharging the effluent into the environment.

1. Introduction

Bangladesh, a developing country, has been industrialized over the last two decades in various sectors. Thousands of textiles in Bangladesh use a huge amount of water, chemicals, and dyes in the finishing and dyeing processes. Particularly, synthetic dyes are extensively used in various branches of the textile industry (Islam and Mostafa, 2018b; Slama et al., 2021), the leather industry (Chowdhury et al., 2015; Monira et al., 2023), the food industry (Zahedi et al., 2020), and so on, producing a huge volume of dyeing effluents. In textiles, 93% of the raw water, used for production, comes out as strongly colored wastewater due to dyes containing high chemical oxygen demand (COD), biological oxygen demand (BOD), a large number of suspended solids, total dissolved solids (TDS), extreme pH, concentrated organic compounds, and heavy metals (Hossen and Mostafa, 2023; Wijannarong et al., 2013). Crops, grown on polluted soils, may cause trace metals to be absorbed and, subsequently, accumulated along the food chain posing potential threats to animal and human health (Dahnoun and Djadouni, 2020). More than 70,000 tons of approximately 10,000 dyes and pigments are produced annually worldwide, of which approximately 20-30% are discharged as effluents from the curing and finishing processes of textiles (Patil and Shrivastava, 2015). About 20–30% of the 10,000 dyes and pigments, used in the textile industry, are reactive dyes, which include azo, anthraquinone, phthalocyanine, formazine, oxazine, etc. (Islam and Mostafa, 2022; Papić et al., 2004). The overwhelming majority of synthetic dyes exhibit a considerable structural diversity, and most of them are azo derivatives. Azo dyes represent about 60% of all reactive dyes utilized by the textile industry. Due to the presence of carcinogenic compounds such as naphthalene, benzamine, and other aromatic compounds, the dye effluent becomes toxic even at its lower concentrations (Gil et al., 2011). The exhaustion properties of azo dyes are poor, and they obstruct light penetration, interrupt photosynthetic movement, and prevent the growth of biota (Tareque et al., 2023; Islam and Mostafa, 2018a). The color of the effluents is aesthetically unpleasant to aquatic bodies. It hinders the oxygenation ability of water, disturbs the whole aquatic ecosystem and food chain, and poses a thoughtful risk to human health. The problem is even more acute in developing countries like Bangladesh, where rapid population growth and industrialization have increased the complexity of wastewater (Rahim and Mostafa, 2021; Saha el al., 2021; Ntuli et al., 2011; Qasim and Mane, 2013).

Hence, there is an urgent requirement for the development of innovative, but low-cost techniques, by which dye molecules can be removed. Many techniques, including coagulation-flocculation, electro-coagulation, adsorption, ion exchange, advanced oxidation processes (O_3/H_2O_2, $H_2O_2/$UV, and photo-catalysis), flotation, membrane techniques (ultra-filtration, nanofiltration, and reverse osmosis), ozonation, radiolysis, and biological degradation, have been successfully used to remove the color from wastewater (Sayed and Mostafa, 2021, 2023; Deng and Zhao, 2015; Fan et al., 2008; Mostafa and Hoinkis, 2012). However, due to

some drawbacks of the aforementioned single process, as wastewater contains a complex mixture of variable contents, conventional techniques could not be implemented at scale in the industry. The C-F technique, coupled with adsorption, offers high efficiency of dye removal, less produced sludge, coagulant savings, and economic feasibility (Papić et al., 2004). Various adsorbents, such as montmorillonite, bentonite clay, nanoparticles, petroleum wastes, tannin-rich materials, sawdust, fly ash, sugar industry wastes, chitosan, peat moss, scrap tires, etc. (Kandisa et al., 2016) and agricultural unused materials include banana peel (Annadurai et al., 2002), rice husk (Malik, 2003), date pit (Banat et al., 2003), almond shell (Ardejani et al., 2008), etc. are being studied for removing of color, COD, and BOD at changed operational settings (Rafatullah et al., 2010). Among the various adsorbents, nanoparticles have drawn great attention due to their outstanding physicochemical properties, including small size, larger surface area, and magnetic properties. Adsorption by nanoparticles is a promising and attractive alternative for the treatment of azo-containing dyes and is inexpensive and readily available. The cost-effectiveness, higher environmental stability, higher adsorption capability, and nontoxic nature of IONPs make them suitable for wastewater treatment (Crane and Scott, 2012). Another exclusive property that favors using IONPs in the field of adsorption is magnetism, which makes the separation process easier. Therefore, IONPs can be easily separated with the help of a magnetic field after the adsorption. Several chemical methods can be used to synthesize IONPs, such as micro-emulsions (Salvador et al., 2021), hydrothermal synthesis (Ge et al., 2009), thermal decomposition (Unni et al., 2017), co-precipitation (Al-Alawy et al., 2018), sol-gel method (Kayani et al., 2014), and the colloidal chemistry method (Krans et al., 2020). Among these, chemical co-precipitation is probably the simplest and most promising method for the production of nanomaterials, as the procedure is relatively simple and a large amount of controlled particle size of IONPs can be synthesized (Al-Alawy et al., 2018). The study synthesized IONPs by co-precipitation of ferric and ferrous ions in an alkaline solution at 80 °C, and, then, it was used for the removal of color, COD, and BOD from textile dyeing effluent. The study aimed to investigate the feasibility of a coagulation process coupled with nanoparticle adsorbents to achieve a higher color removal efficiency in treating textile dye effluents.

2. Materials and Methods

2.1 Sample collection and analysis for characterization

The textile dyeing effluent was collected in a five-liter pre-washed plastic container from Sirajganj District in Bangladesh. Before sampling, the containers were washed with diluted acid and double distilled water, and just before sampling, they were rinsed with the effluents to be sampled. pH, dissolved oxygen (DO), and electrical conductivity (EC) were measured on the spot by a portable multimeter. A few mL of concentrated HNO_3 and HCl were added to the effluent to prevent the growth of microbial bacteria, and the containers were sealed to prevent air oxidation. The effluents were analyzed before and after treatment using different analytical techniques, including titration, gravimetric, and spectrophotometric methods. Some of the physicochemical parameters were determined as per standard methods (APHA, 2012).
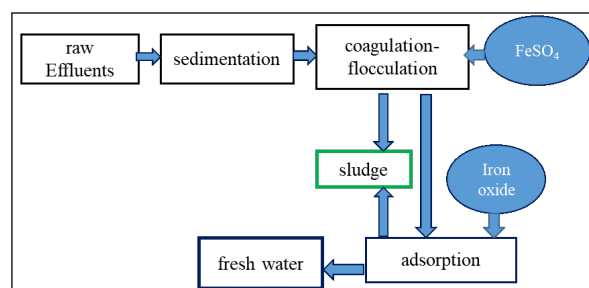

Figure 1. Flow chart of the experiment

2.2 Coagulation-flocculation experiments

Figure 1 shows a simplified experimental setup that describes different stages of C-F and adsorption processes. The collected effluents were kept overnight for sedimentation. It was then placed in the jar test apparatus for C-F experiments, and the supernatant, obtained after C-F, was subjected to the adsorption process to get fresh water. The C-F process was conducted to obtain optimal process parameters, such as, coagulant doses (100 mg/L to 1200 mg/L), pH (3 to 12), temperature (25 to 50 °C), contact time (15 to 180 min.), and mixing speed (30 to 180 rpm). Each beaker was filled with the desired volume of effluent and added the desired amount of coagulant dose. The solution was stirred rapidly for 1.5 min. to ensure complete dispersion of the coagulants, followed by slow mixing to aid in the formation of flocs. The pH of the sample was adjusted in the range of 3-12 with 0.01 M HCl and/or 0.01 M NaOH solution before being subjected to the jar test. At the end of the sedimentation period, the supernatant was collected from the top of the beaker and the absorbance was measured using UV-visible spectrophotometer (SHIMADZU UV-mini1240) of the treated effluents at its λ_{max}. All experiments were conducted thrice and mean values were taken. The color removal percentage was calculated using the following equation (Hoong and Ismail, 2018):

$$\text{Color removal (\%)} = \frac{A_0 - A_f}{A_0} \times 100 \qquad (1)$$

where A_0 and A_f are the initial and final absorbance of the untreated and treated effluents, respectively.

2.3 Batch adsorption experiments

After C-F experiments, batch adsorption studies were carried out at different doses (0.5 to 3.0 g/L) of synthesized IONPs adsorbent, keeping other parameters constant. Then, the adsorption of color was studied at pH values of 2.0 to 12.0 at different contact times (10, 15, 20, 30, 45, 60, 90, 120, and 180 min.) at 30 °C to get the optimum values. The experimental procedure is as follows: 100 mL of effluent was taken in 250 mL beakers loaded with a definite dose of IONPs after adjusting the pH of the effluent with 0.01 M HCl and/or 0.01 M NaOH solutions. The solution was stirred vigorously in an electric shaker at 180 rpm for a predefined time, and the beaker was, then, placed on the magnet. The effluents became colorless due to the magnetic separation of dye-loaded adsorbents. The mixture was decanted to measure its concentration with a UV-visible spectrophotometer by

measuring the absorbance at a wavelength corresponding to the maximum absorbance of the sample. All batch adsorption studies were conducted three times, and mean values were taken. The color removal efficiency of the adsorption process was calculated using the same equation used in the coagulation process stated above.

2.4 Adsorption kinetics

The pseudo-first-order equation and pseudo-second-order equation are used to illustrate the adsorption kinetics of the adsorbent surfaces. The pseudo-first-order equation can be expressed in the following form (Ho and McKay, 1998; Mostafa et al., 2011):

$$log(q_e - q_t) = log(q_e) - \frac{k_1}{2.303}t \qquad (2)$$

where q_e and q_t are the amounts of adsorbate adsorbed (mg g^{-1}) at equilibrium and at time t (min.) respectively, and k_1 is the pseudo-first-order rate constant (L min^{-1}).

The pseudo-second-order equation can be stated as the following (Ho and McKay, 1999):

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e}(t) \qquad (3)$$

where k_2 is the rate constant of pseudo-second-order adsorption (g mg^{-1}min^{-1}).

3. Results and Discussion

3.1 Characterization of the effluents

Table 1 shows the physicochemical characteristics of the effluent. The collected effluents were highly colored and aesthetically unpleasant, and the values of all the parameters exceeded the DoE-BD standard, indicating that the wastewater was extremely polluted. Due to its color and higher levels of pollutants, the wastewater cannot be disposed of in any treatment plants before a pre-treatment stage. The untreated wastewater discharge has potential threats to surface water quality, aquatic life, and the entire environment. Therefore, it is imperative to improve the treatment method to reduce the impact of the effluents on the environment. Hence, the study looked for ways to improve the treatment of dyeing effluents through coagulation with FeSO$_4$, coupled with adsorption on nanoparticles.

Table 1. Physicochemical characteristics of the effluents

Parameters		Color	pH	EC, µS/cm	TDS, mg/L	TSS, mg/L	DO, mg/L	COD mg/L	BOD mg/L
Results	Ef1	pink red	11.3	6240	4337	475	1.4	3732	1156
	Ef2	greenish black	11.2	6082	4025	400	1.6	3480	1065
DoE standard		-	6-9	1200	2100	150	-	200	50

3.2 Optimization of Coagulant

3.2.1 Effect of coagulant dose

In the C-F process, the dose is one of the most important factors to consider. Essentially, a small dose or overdosing would result in poor flocculation. The effects of coagulant doses (100-1200 mg/L) on the removal of color were shown in Figure 2, which illustrates that for small dosages (especially below 500 mg/L), color removal was rather low, while for 700 mg/L dosages, the removal efficiency of color was around 73%. The color removal efficiency of FeSO$_4$ coagulant increased gradually with dose due to the higher positive charge and polymeric effects of FeSO$_4$ (Joo et al., 2007). Furthermore, the high concentrations (>700 mg/L) of the coagulant may confer positive charges on the particle surface (a positive zeta potential), thus re-dispersing the particles, resulting in a decrease in color removal (Patel and Vashi, 2015). A similar result was observed in the ferrous sulfate coagulant, which showed more than 90% color removal efficiency at a coagulant dosage of 1600 mg/L (Jindal et al., 2016).
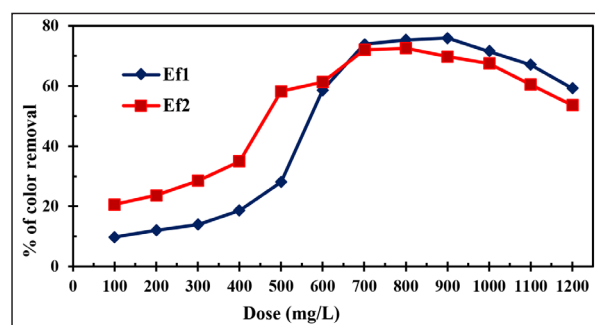
3.2.2 Effects of pH

One of the most important variables in the coagulation process using inorganic salts is the pH. This is because the inorganic coagulant is converted into different ionic species as the pH value changes, thus influencing the coagulation (Rodrigues et al., 2013). Figure 3 shows a decrease in percentage removal with an increase in pH for Ef1, but the percentage removal is increasing for Ef2 at pH ranges from 3 to 5. This is because, in the acidic region, Fe salt hydrolyzes to form monomeric Fe hydrolyzed species. Hence, soluble Fe^{2+} and Fe(OH)$^+$ cations play an important role in destabilizing the negatively charged dye particles via charge neutralization, and thus color removal takes place at lower pH but too little because of the lack of formation of neutral Fe(OH)$_2$ precipitates (Wong et al., 2007). The formation of Fe^{2+}, Fe(OH)$^+$, and neutral Fe(OH)$_2$ hydrolysis species with large surface areas capable of adsorbing soluble dye is maximized at an alkaline pH, and color removal occurs via charge neutralization and sweep flocculation (Perng and Bui, 2014; Suman et al., 2018). The maximum color removal efficiency of FeSO$_4$ was about 75% at the optimum pH of 11.0. A study showed that each coagulant was effective in decolorization within a specific pH range, which depended strongly on the nature of the wastewater, and the color removals were 91.4% for cotton at pH 9.4 and 93.8% for acrylic effluents at pH 8.3, respectively, using FeSO$_4$ coagulant (Rodrigues et al., 2013). At another pH, the complexes of hydrolysis products caused a decrease in the removal efficiency (Perng and Bui, 2014).
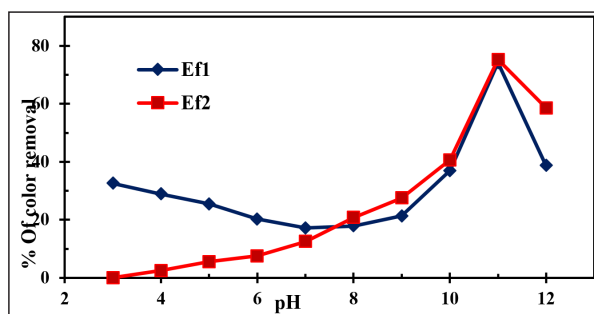

Figure 2. Effect of coagulant dose on color removal efficiency [pH 11.30, T 30 °C, contact time 30 min., and mixing speed 30 min.]

Figure 3. Effects of pH on color removal efficiency for Ef1 and Ef2 samples [coagulant dose 700 mg/L, temp 30 °C, contact time 30 min., and mixing speed 30]

3.2.3 Effects of temperature

Temperature affects the solubility of the metal hydroxide precipitate and the rate of formation of the metal hydrolysis products. Low temperature affects coagulation processes by altering coagulant solubility, increasing water viscosity, and retarding the kinetics of hydrolysis reactions. As shown in Figure 4, the effect of temperature on color removal is marked, increasing from 58% at 25°C up to 73% at 35°C for Ef1 and 68% to 76% for Ef2, and the % removal was not increased further up to 50°C, rather slightly decreasing for both effluents. This is because coagulation with hydrolyzing metals is less efficient at lower temperatures and has a pronounced detrimental effect on flocculation kinetics (Duan and Gregory, 2003). It has been reported that a decrease in temperature, (0-24°C), impairs the flocs› strength and virtually the flocs› formation efficiency, which results in a decrease in aggregation rate and bad settling (Fitzpatrick et al., 2004). The increased performance with temperature may be a consequence of the improved kinetics as occurs in most chemical reactions (Rodrigues et al., 2013). As the temperature increases from 30 to 35°C, the viscosity of the water decreases, and brown movement becomes fierce gradually as a result of the hydrolysis of the Fe(II) ion and increased competition for bonding by the macromolecules, and this accelerates the coagulation processes (Misau and Yusuf, 2016). The reasons behind decreased performance above 35°C were floc breakage increases, and floc reformation decreases at higher temperatures. Warmer temperatures generally produce bigger flocs that break more easily and reform less well, suggesting a weaker floc settlement. At high temperatures (above 35 °C), breakage in terms of floc size reduction is greater (Brabty, 2006).
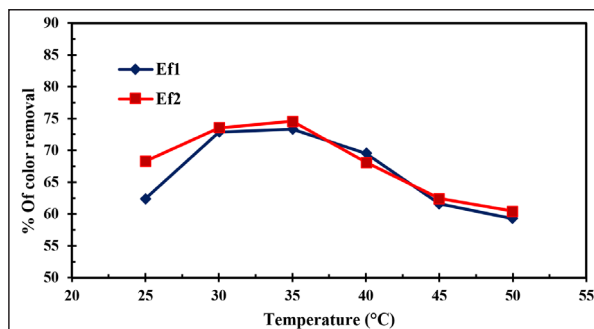

Figure 4. Effect of temperature on color removal efficiency for effluent Ef1 and Ef2 [coagulant dose 700 mg/L, pH 11.00, mixing speed 30 and settling time 30 min]

3.2.4 Effect of contact time

Contact time plays a vital role in flocs formation and growth in the flocculation process. The effect of contact time on the coagulation of dyeing effluents was studied using a time range of 15 min. to 180 min. and keeping other parameters constant. The trends that had been illustrated in Figure 5 showed that a longer or shorter contact time would result in poor performance of $FeSO_4$ for binding and bridging in the case of both effluents. In a short period, the collisions between the flocculants and colloids are not efficient to precipitate suspended solids. The color removal efficiency significantly dropped from 73% to about 56% with increasing reaction time from 30 min. to 180 min. for Ef1 and 73% to 53% for Ef2, respectively. This is because longer mixing times lead to an increase in floc breakage and limit the size of the flocs formed. The small-size flocs are not dense enough to settle down and thus, indirectly cause the sample to be turbid again (Hassan et al., 2009). This phenomenon is observed in Figure 5, which shows a lower percentage of reductions at longer contact times (i.e., 180 minutes). Similar results were reported as the restabilization phenomenon by Klimiuk et al. (1999).
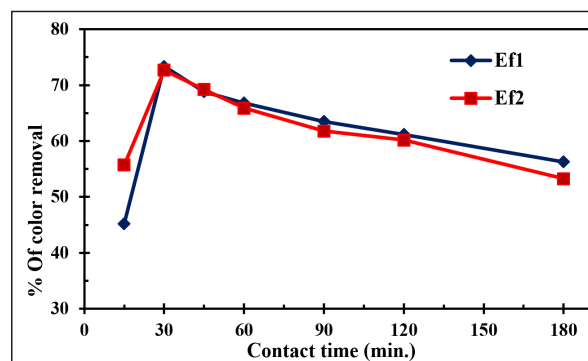

Figure 5. Effects of contact time on color removal efficiency for effluent Ef1 and Ef2 [coagulant dose 700 mg/L, pH 11.00, temp. 30 °C, mixing speed 30 and settling time 30 min.]

3.2.5 Effects of mixing speed

Mixing speed is one of the important factors in achieving higher color removal efficiency of the coagulants during the coagulation process. In this study, the effects of agitation speeds between 15 and 180 rpm were investigated. The results showed that the color removal efficiency of $FeSO_4$ increased with increasing mixing speeds between 15 and 45 rpm. These results might be caused by the fast flocs formation and high sludge precipitation rates of the inorganic coagulant. The color removal efficiency gradually decreased as the agitation speed increased. This trend showed that floc formation and breakage were intensely affected by the mixing rate (Xu et al., 2010). The highest color removal might be caused by increasing shear stress and breakage of flocs with increasing agitation speed. Figure 6 shows that the color removal efficiency was about 75% and 76% for Ef1 and Ef2, respectively, at an optimum mixing speed of 45 rpm. Similar results were observed in an experiment, which showed that about 74% of color removal was obtained by $FeSO_4$ for the cotton dyeing effluent (Xu et al., 2010).
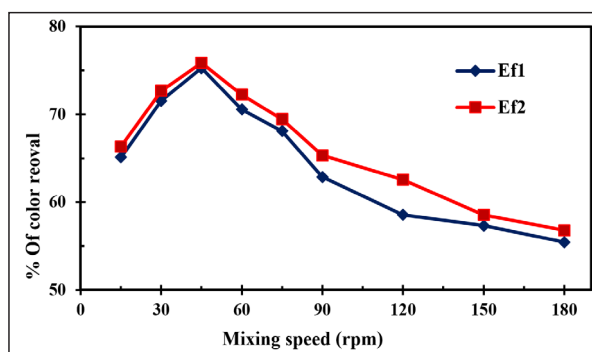
Figure 6. Effects of mixing speed on color removal efficiency for Ef1 and Ef2 [dose 700 mg/L, pH 11.00, temp. 30°C, and contact time 30 min.]

3.3 Adsorption followed by coagulation

Adsorption can be an effective and versatile method for wastewater treatment, particularly when combined with chemical treatment methods. For better effluent treatment, optimal adsorption conditions must be determined. Several studies have illustrated that optimizing the parameters greatly influences the adsorption efficiencies of color and COD (Nayl et al., 2017; Nure et al., 2017; Wasti and Awan, 2016).

3.3.1 Effects of adsorbent dose

Figure 7 shows the effect of varying the adsorbent dose on the adsorption of color from effluents. The percentage of color removal increased with increasing doses from 1.0 to 3.0 g/L up to a maximum, after which increasing the dose of IONPs did not improve color removal. This is because the active sites could be effectively utilized when the dose was low. But at higher adsorbent dosages, it is more likely that a significant portion of the available active sites remains uncovered, leading to lower specific uptake (Patel and Vashi, 2010). The number of active sites for the sorption also increases by increasing the adsorbent dose, thus increasing the amount of adsorption. When the surface active sites are covered completely, the extent of adsorption reaches equilibrium (Zobayer et al., 2013). So, it is clear that equilibrium was attained after a dose of 1.5 g/L. The maximum removal efficiencies found were 94% and 95% for Ef1 and Ef2, respectively, at doses of 1.5 g/L for both effluents.
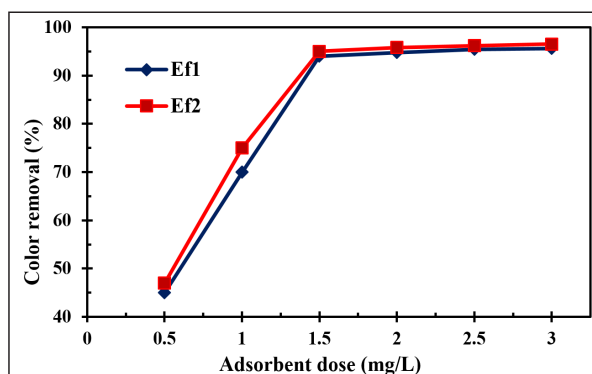

Figure 7. Effects of adsorbent dose on color removal efficiency (pH 7.0, contact time 30 min., temp. 30°C, and mixing speed 180 rpm)

3.3.2 Effects of pH

pH is an important parameter that affects the adsorption of dye molecules. The effect of the initial pH of the textile effluents on dye adsorption onto IONPs was assessed at different pH values, ranging from 2 to 12, with an optimum dose. Figure 8 shows that the maximum color removal was obtained around the neutral pH. Nevertheless, at optimum pH 6.0, more than 95 % and 96% of the color for Ef1 and Ef2, respectively, was removed by IONPs. The results showed that the adsorption was favorable in both acidic and basic environments. The electrostatic interactions between the nanoparticle surface and the functionalized dye molecule play a crucial role in the adsorption of dyes by IONPs. These interactions are greatly influenced by the pH of the sample, as it directly affects the surface charge of the nanoparticles. As the pH of zero-point charge (pHpzc) of IONPs is around 7.5 (Nassar and Ringsred, 2012), the adsorption of ionized dye on iron oxide surfaces could be due to electrostatic attraction. The surface charge is positive at pH values lower than pHzpc, neutral at pHzpc and negative at pH values higher than it. Therefore, in a relatively basic solution, pH >pHpzc, there is a high electrostatic attraction between the negatively-charged iron oxide and the positively-charged dye molecules. In contrast, as the pH of the solution falls, the proportion of positively charged sites rises while the proportion of negatively charged sites falls. This led to increased negatively charged dye adsorption but a decrease in positively-charged dye adsorption (Nassar et al., 2015). Simply to say, lower pH favors anionic dye adsorption and higher pH cationic dye adsorption and vice-versa (Salleh et al., 2011). In this study, the adsorptive dye removal was not significantly affected by solution pH, which suggests that the dye present in the textile wastewater sample might be multifunctional, and accordingly, it could be adsorbed in either basic or acidic environments (Nassar et al., 2015).
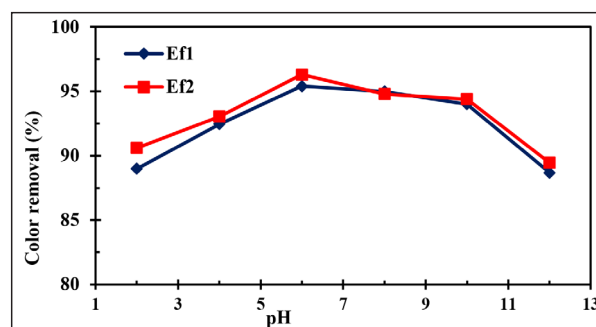

Figure 8. Effects of pH on the color removal efficiency of adsorbent (dose 1.5 g/L, contact time 30 min, temp. 30°C, and mixing speed 180 rpm)

3.3.3 Effects of contact time

Figure 9 shows the adsorption of color by IONPs as a function of contact time from 05 to 180 minutes at an adsorbent dose of 1.5 g/L at 30 °C for both effluents at pH 6.0. As seen, the adsorption was very rapid at the initial stages and then approached equilibrium just after 45 minutes i.e., the adsorption capacity increases with the increase in contact time until equilibrium is reached (Al-trawneh, 2015). This may be due to the larger surface area of IONPs at the very beginning of color adsorption. As the adsorption sites are depleted, the rate at which the dye molecules are

transported from the exterior to the interior sites of the adsorbent particles controls the dye uptake rate (Patel and Vashi, 2010). At equilibrium, about 96% and 98% of color were removed from Ef1 and Ef2, respectively (Figure 9). The relation between the removal of dyes and contact time was studied by (Hashemian et al., 2013), where adsorption increased with an increase in contact time. It was found that more than 75% of the dye removal occurred in the first 45 min., and thereafter the rate of adsorption was found to be slow. The rapid adsorption was due to the availability of the surface porosity of the adsorbent, which led to fast adsorption of dyes, the later slow rate of adsorption is due to the slow pore diffusion of the solute ion into the bulk of the adsorbent. El-Sayed et al. (2014) studied that the removal rapidly increased in the first 10 min. but then slowly increased to reach equilibrium because of the strong attraction forces between methylene blue dye and the adsorbent.
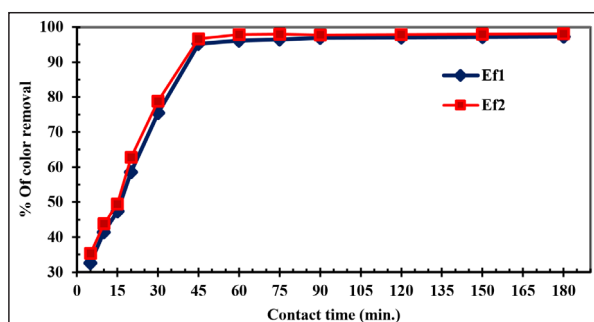

Figure 9. Effects of contact time on color removal efficiency for Ef1 and Ef2 (dose 1.5 g/L, temp. 30°C, and mixing speed 180 rpm)

3.4 Adsorption kinetics

The experimental data were fitted to the pseudo-first-order and pseudo-second-order equations as shown in Figure 10 and Figure 11. The higher R^2 values of the experimental data (greater than 0.99) and good agreement of the calculated q_e values with that of the experimental qe values at 30 °C (Table 2), recommended that the adsorption procedure followed a pseudo-second order kinetic reaction mechanism (Jafar et al., 2015).
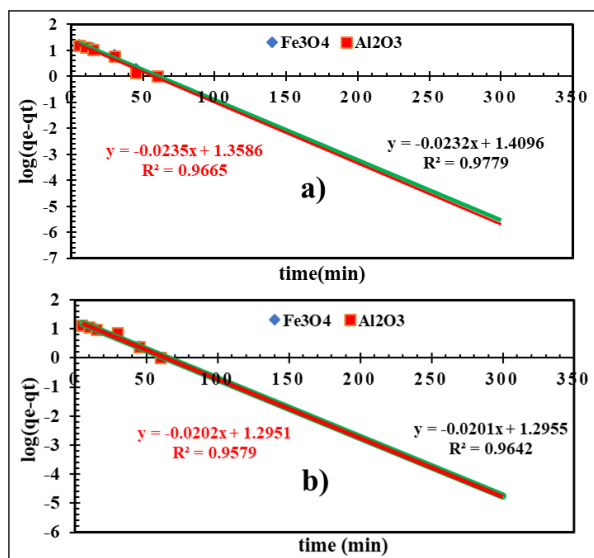

Figure 10. Pseudo -1st order kinetic plots of adsorption for textile dyeing effluents a) Ef1, and b) Ef2 onto IONPs
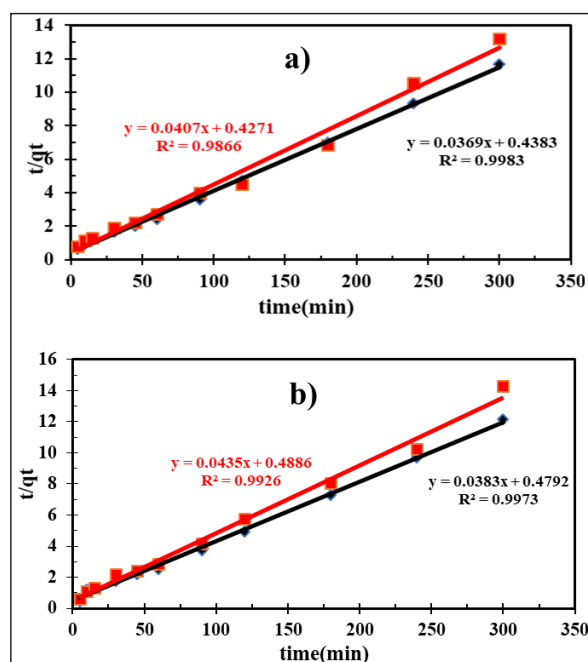

Figure 11. Pseudo -2nd order kinetic plots of adsorption for textile dyeing effluents a) Ef1, and b) Ef2 onto IONPs

Table 2. Kinetic parameters calculated by pseudo-first-order and pseudo-second-order equations for dyes adsorbed on IONPs

Parameters	Pseudo-first-order kinetics		Pseudo-second-order kinetics	
	Ef1	Ef2	Ef1	Ef2
Rate constant	0.0534	0.0462	3.12×10^{-3}	3.06×10^{-3}
q_e cal. (mg/g)	25.68	19.74	27.70	26.11
q_e exp. (mg/g)	24.86	23.85	25.68	19.74
R^2	0.9779	0.9642	0.9983	0.9973

3.5 Comparative studies

It has been reported by different researchers that the percentages of color removal were in the range of 6 to 74.5, using various inorganic coagulants such as $MgCl_2$, $FeSO_4$, lime, PAC, and ferric sulfate as shown in Table 3, even though the dosage was high. Alum removed about 74% color but the dosage was too high. In the present study, $FeSO_4$ coagulant proved effective as it removes 75.3%, and 76.0% color from real textile effluents Ef1 and Ef2, respectively. It indicates that different coagulant was suitable for the treatment of various types of the textile dyeing effluents.

Table 4 compares the maximum dye adsorption capacity of IONPs and other adsorbents published in the literature. In comparison, it is clear that the maximum adsorption capacity of IONPs is superior to most of other adsorbents. Although the adsorption capacity of Palladium nanoparticles AC and alumina nanoparticles is also high, the use of synthetic IONPs is much more economical than other adsorbents due to their large surface area, economic feasibility, and small diffusion resistance (Afkhami et al., 2010). Moreover, the adsorbed dye can be easily desorbed to free the adsorbent, which could be further used to treat wastewater. This suggests that the adsorption property of IONPs gives the material great potential for applications in color and COD removal from wastewater.

Table 3. Comparison of ferrous sulfate with different coagulants in color removal from textile effluents

Coagulant	Dyes / Effluents	Dose (mg/L)	% of color removal	Reference
$MgCl_2$	Effluents	2000	62	(Mohamed et al., 2014)
$FeSO_4$	textile wastewater	200	6	(Patabandige et al., 2020)
Lime	Textile effluent	700	53.9	(Zorpas et al., 2012)
PAC	Textile wastewater	30	44.5	(Bazrafshan et al., 2015)
$Fe_2(SO_4)_3$	Textile wastewater	70000	57.9	(Patel and Vashi, 2010)
Alum	Dyeing wastewater	5000	74	(Kumar et al., 2008)
Alum	Textile wastewater	70000	74.5	(Patel and Vashi, 2010)
$FeSO_4$	Dyeing effluent (Ef1)	700	75.3	This study
$FeSO_4$	Dyeing Effluent (Ef2)	700	76.0	This study

Table 4. Comparison of iron oxide nanoparticle and other adsorbents for dye removal from the dyeing effluents

Adsorbent	Dyes	Maximum adsorption capacity, (mg/g)	References
Palladium nanoparticles AC	Congo red	126.58	(Ahmadi et al., 2015)
TiO_2/GMAC	Reactive Black 5	56	(Belayachi et al., 2015)
Bentonite clay	Reactive Black 5	29.38	(Amin et al., 2015)
Kaolin	Procion brilliant red	3.51	(Rahman et al., 2013)
Sepiolite	Reactive Yellow 138:1	3.23	(Rahman et al., 2015)
Alumina nanoparticle	Color black G	263.16	(Bhargavi et al., 2015)
Sawdust Carbon	Methylene blue	12.49 - 51.4	(Salleh et al., 2011)
Ficus Carica Bast AC	Methylene blue	30-45	(Pathania et al., 2017)
Magnetite nanoparticle	Mixture of dyes (Ef1)	208.3	This study
Magnetite nanoparticle	Mixture of dyes (Ef2)	39.2	This study

3.6 Economic feasibility study

The study selected the best coagulant and adsorbent in terms of color and COD removal efficiency and compared with other treatment methods in terms of cost-effectiveness, as shown in Table 5. The economic feasibility study mainly focused on the total costs of chemical reagents. The main chemicals used in the treatment processes were $FeSO_4$ for the C-F process and synthesized Fe_3O_4 nanoparticles for adsorption. The quantity of coagulant and adsorbent required for 1 m³ was calculated from the quantity of coagulant and adsorbent required for 1 L of effluent. The operating cost was calculated based on the recent market price in December, 2023. In comparison with other research, the present study achieved the highest percentage of color removal with the lowest cost.

Table 5. Comparison of the treatment cost with others

Sample	Coagulant + adsorbent	Amount (Kg/m³)	% of color/COD removal	Cost ($/m³)	Reference
Effluent	$Fe_2(SO_4)_3$ + Activated carbon	70 + 9	71.4	86.5	(Patel and Vashi, 2010)
Textile effluents	$Al_2(SO_4)_3$	0.6	93.12	0.75	(Couto Junior et al., 2013)
Effluent	$Al_2(SO_4)_3$ + Activated carbon	1 + 1	48.20	1.960	(Mukherjee, 2014)
Ef1	$FeSO_4$ + IONPs	0.6 + 2.5	99.0	0.45	This study
Ef2	$FeSO_4$ + IONPs	0.6 + 2.5	99.5	0.45	This study

4. Conclusion

The study used FeSO4 as a coagulant and synthesized IONPs as adsorbents to determine the effectiveness of these materials for removing color from dyeing effluents. The IONPs were synthesized by a simple co-precipitation method controlled by the pH and temperature of the reaction media. The X-RD analysis results confirmed that the synthesized iron-oxide particles were found to be within the nano-size range (10–20 μm). The optimal conditions for coagulation-flocculation (C-F) treatment were found at pH 11.0, coagulant dose 700 mg/L, reaction time 30 min, mixing speed 45 rpm, and temperature 30 °C, at which the color removal efficiency was about 75 %. The study showed that a combination of coagulation and adsorption on IONPs for the discoloration of textile effluents was more efficient than the coagulation-flocculation process alone. In the combination process, more than 99.5% color removal was achieved for both effluents. The SEM images showed the rough and porous surface of virgin IONPs having a slightly hazy and smooth surface for the adsorbed IONPs. The EDS analysis confirmed the presence of various metal ions on the IONPs surface. Finally, it can be concluded that the combination of chemical

coagulation and adsorption processes has the potential to remove color from textile wastewater.

Conflict of Interest:

The authors ensured that there was no direct or indirect involvement of human, animal, or any biological elements that have been tested that may arise any conflict of interest in this research. Moreover, the authors declare that they have no conflicts of interest in the subject matter or materials discussed in the manuscript.

Acknowledgements

References

Afkhami, A., Saber-Tehrani, M., and Bagheri, H. (2010). Modified maghemite nanoparticles as an efficient adsorbent for removing some cationic dyes from aqueous solution. Desalination, 263(1-3): 240–248. https://doi.org/10.1016/j.desal.2010.06.065

Ahmadi, K., Ghaedi, M., and Ansari, A. (2015). Comparison of Nickel Doped Zinc Sulfide and/or Palladium Nanoparticle Loaded on Activated Carbon as Efficient Adsorbents for Kinetic and Equilibrium Study of Removal of Congo Red Dye. Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy, 136 (Part C) : 1441 - 1449, doi:10.1016/j.saa.2014.10.034.

Al-Alawy, A.F., Al-Abodi, E.E., and Kadhim, R.M. (2018). Synthesis and Characterization of Magnetic Iron Oxide Nanoparticles by Co-Precipitation Method at Different Conditions. Journal of Engineering, 24(10): 60-72. https://doi.org/10.31026/j.eng.2018.10.05

Al-trawneh, S. A. (2015). Studies on Adsorptive Removal of Some Heavy Metal Ions by Calix [4] Resorcine, Jordan Journal of Earth and Environmental Sciences Volume, 7(1): 1-9.

Amin, M.T., Alazba, A.A., and Shafiq, M. (2015). Adsorptive Removal of Reactive Black 5 from Wastewater Using Bentonite Clay: Isotherms, Kinetics and Thermodynamics. Sustainability, 7(11): 15302-15318, doi:10.3390/su71115302.

Annadurai, G., Juang, R.S., and Lee, D.J. (2002). Use of cellulose-based wastes for adsorption of dyes from aqueous solutions. Journal of Hazardous Materials, 92(3): 263-274. https://doi.org/10.1016/S0304-3894(02)00017-1

APHA. (2012). Standard methods for examination of water and waste water. 20th Ed., American Public Health Association. http://books.google.com/books?id=buTn1rmfSI4C&pgis=1

Ardejani, F.D., Badii, K., Limaee, N.Y., Shafaei, S.Z., and Mirhabibi, A.R. (2008). Adsorption of Direct Red 80 dye from aqueous solution onto almond shells: Effect of pH, initial concentration and shell type. Journal of Hazardous Materials, 151(2-3): 730-737. https://doi.org/10.1016/j.jhazmat.2007.06.048

Banat, F., Al-Asheh, S., and Al-Makhadmeh, L. (2003). Evaluation of the use of raw and activated date pits as potential adsorbents for dye containing waters. Process Biochemistry, 39(2): 193-202. https://doi.org/10.1016/S0032-9592(03)00065-7

Belayachi, H., Bestani, B., Benderdouche, N., and Belhakem, M. (2015). The Use of TiO2 Immobilized into Grape Marc-Based Activated Carbon for RB-5 Azo Dye Photocatalytic Degradation. Arabian Journal of Chemistry, 12(8): 1-10. doi:10.1016/j.arabjc.2015.06.040.

Bhargavi, R.J., Maheshwari. U., and Gupta, S. (2015). Synthesis and Use of Alumina Nanoparticles as an Adsorbent for the Removal of Zn(II) and CBG Dye from Wastewater. International Journal of Industrial Chemistry, 6(1): 31-41, doi:10.1007/s40090-014-0029-1.

Brabty, J. (2006). Coagulation and flocculation in water and waste water treatment, 2nd Ed., IWA publishing.

Bazrafshan, E., Alipour, M.R., and Mahvi, A.H. (2015). Textile Wastewater Treatment by Application of Combined Chemical Coagulation, Electrocoagulation, and Adsorption Processes. Desalination and Water, 57(20): 1-13, doi: 10.1080/19443994.2015.1027960

Chowdhury, M., Mostafa, M.G., Biswas, T.K., Mandal, A., and Saha, A.K. (2015). Characterization of the Effluents from Leather Processing Industries. Environmental Processes, 2(1): 173-187. https://doi.org/10.1007/s40710-015-0065-7

Couto Junior, O.M., Barros, M.A.S.D., and Pereira, N.C. (2013). Study on coagulation and flocculation for treating effluents of textile industry. Acta Scientiarum -Technology, 35(1): 83-88. https://doi.org/10.4025/actascitechnol.v35i1.11685

Crane, R.A., and Scott, T.B. (2012). Nanoscale zero-valent iron: Future prospects for an emerging water treatment technology. Journal of Hazardous Materials, 211-212: 112-125. https://doi.org/10.1016/j.jhazmat.2011.11.073

Deng, Y., and Zhao, R. (2015). Advanced Oxidation Processes (AOPs) in Wastewater Treatment. Current Pollution Reports, 1: 167-176. doi:10.1007/s40726-015-0015-z

Dahnoun, K., and Djadouni, F. (2020). Effects of Heavy-Metal Pollution on Soil Microbial Community, Plants, and Human Health, Jordan Journal of Earth and Environmental Sciences, 11(3): 234-240.

Duan, J., and Gregory, J. (2003). Coagulation by hydrolysing metal salts. Advances in Colloid and Interface Science, 100-102: 475-502. https://doi.org/10.1016/S0001-8686(02)00067-2

El-Sayed, G.O., Yehia, M.M., and Asaad, A.A. (2014). Assessment of activated carbon prepared from corncob by chemical activation with phosphoric acid. Water Resources and Industry, 7-8: 66-75. https://doi.org/10.1016/j.wri.2014.10.001

Fan, L., Zhou, Y., Yang, W., Chen, G., and Yang, F. (2008). Electrochemical degradation of aqueous solution of Amaranth azo dye on ACF under potentiostatic model. Dyes and Pigments, 76(2): 440-446. https://doi.org/10.1016/j.dyepig.2006.09.013

Fitzpatrick, C.S.B., Fradin, E., and Gregory, J. (2004). Temperature effects on flocculation, using different coagulants. Water Science and Technology, 50(12): 171-175. https://doi.org/10.2166/wst.2004.0710

Gao, B.Y., Yue, Q.Y., Wang, Y., and Zhou, W.Z. (2007). Color removal from dye-containing wastewater by magnesium chloride. Journal of Environmental Management, 82(2): 167-172. https://doi.org/10.1016/j.jenvman.2005.12.019

Ge, S., Shi, X., Sun, K., Li, C., Uher, C., Baker, J.R., Banaszak Holl, M.M., and Orr, B.G. (2009). Facile hydrothermal synthesis of iron oxide nanoparticles with tunable magnetic properties. Journal of Physical Chem C. 113(31): 13593-13599. doi.org/10.1021/jp902953t

Gil, A., Assis, F.C.C., Albeniz, S., and Korili, S.A. (2011). Removal of dyes from wastewaters by adsorption on pillared clays. Chemical Engineering Journal, 168(3): 1032-1040. https://doi.org/10.1016/j.cej.2011.01.078

Harrelkas, F., Azizi, A., Yaacoubi, A., Benhammou, A., and Pons, M.N. (2009). Treatment of textile dye effluents using coagulation-flocculation coupled with membrane processes or adsorption on powdered activated carbon. Desalination, 235(1-3): 330-339. https://doi.org/10.1016/j.desal.2008.02.012

Hashemian, S., Salari, K., Salehifar, H., and Yazdi, Z.A. (2013). Removal of azo dyes (violet B and violet 5R) from aqueous solution using new activated carbon developed from orange peel. Journal of Chemistry, 2013(8): 1-10. https://doi.org/10.1155/2013/283274

Hassan, M.A.A., Li, T.P., and Noor, Z.Z. (2009). Coagulation and Flocculation Treatment of Wastewater in Textile Industry

Using Chitosan. Journal of Chemical and Natural Resources Engineering, 4(1): 43-53. http://www.fkkksa.utm.my/jcnre/images/Vol4/dr.

Hoong, H.N.J., and Ismail, N. (2018). Removal of Dye in Wastewater by Adsorption-Coagulation Combined System with Hibiscus sabdariffa as the Coagulant. MATEC Web of Conferences, 152(01008): 1-14. https://doi.org/10.1051/matecconf/201815201008

Ho, Y.S., and McKay, G. (1998). A Comparison of Chemisorption Kinetic Models Applied to Pollutant Removal on Various Sorbents. Process Safety and Environmental Protection, 76(4): 332-40, doi:10.1205/095758298529696.

Ho, Y.S., and McKay, G. (1999). Pseudo-Second Order Model for Sorption Processes. Process Biochemistry, 34: 451-65.

Ho, Y.S., and McKay, G. (2000). The Kinetics of Sorption of Divalent Metal Ions onto Sphagnum Moss Peat. Water Research, 34(3): 735-742, doi:10.1016/S0043-1354(99)00232-8

Hossen, M.A. and Mostafa, M.G. (2023). Assessment of heavy metal pollution in surface water of Bangladesh. Environmental Challenges, 13:100783. doi.org/10.1016/j.envc.2023.100783

Islam, M.R., and Mostafa, M.G. (2022). Adsorption kinetics, isotherms and thermodynamic studies of methyl blue in textile dye effluent on natural clay adsorbent. Sustainable Water Resources Management, 8:52 (Springer). https://doi.org/10.1007/s40899-022-00640-1

Islam, M.R., and Mostafa, M.G. (2018a). Removal of a Reactive Dye from Synthetic Wastewater Using PAC and Fecl3 Coagulants. J. Life Earth Sci., 13: 39-44.

Islam, M.R., and Mostafa, M.G. (2018b). Textile Dyeing Effluents and Environment Concerns - A Review. Journal of Environmental Science and Natural Resources, 11(1-2): 131-144. https://doi.org/10.3329/jesnr.v11i1-2.43380

Jafar, B.M., Hamadneh, I., Khalili, F.I., and Al-dujaili, A.H. (2015). Kinetic Study on Adsorption of Fatty HydroxamicAcids by Natural Clays. Jordan Journal of Earth and Environmental Sciences, 7(1): 11-17.

Jindal, A., Sharma, P.S.K., Jyothi, P.M. (2016). Colour and COD Removal in Textile Effluents using Coagulation Flocculation. International Journal of Innovative Research in Science, Eng. and Tech., 5(6): 10233-10239. https://doi.org/10.15680/IJIRSET.2015.0506139

Joo, D.J., Shin, W.S., Choi, J.H., Choi, S.J., Kim, M.C., Han, M.H., Ha, T.W., Kim, Y.H. (2007). Decolorization of reactive dyes using inorganic coagulants and synthetic polymer. Dyes and Pigments, 73: 59-64. https://doi.org/10.1016/j.dyepig.2005.10.011

Junior, O.M.C., Barros, M.A.S.D., Pereira, N.C. (2013). "Study on Coagulation and Flocculation for Treating Effluents of Textile Industry." Acta Scientiarum -Technology, 35(1): 83-88, doi:10.4025/actascitechnol.v35i1.11685.

Kandisa, R.V., KV, N.S., Shaik, K.B., and Gopinath, R. (2016). Dye Removal by Adsorption: A Review. Journal of Bioremediation & Biodegradation, 7(6): 1-4. https://doi.org/10.4172/2155-6199.1000371

Karadag, D., Tok, S., Akgul, E., Ulucan, K., Evden, H., and Kaya, M.A. (2006). Combining adsorption and coagulation for the treatment of azo and anthraquinone dyes from aqueous solution. Industrial and Engineering Chemistry Research, 45(11): 3969-3973. https://doi.org/10.1021/ie060164+

Kayani, Z.N., Arshad, S., Riaz, S., and Naseem, S. (2014). Synthesis of Iron Oxide Nanoparticles by Sol-Gel Technique and Their Characterization. IEEE Transactions on Magnetics, 50(8): https://doi.org/10.1109/TMAG.2014.2313763

Khatun, M.H., and Mostafa, M.G. (2022). Optimization of Dyeing Process of Natural Dye Extracted from Polyalthia longifolia Leaves on Silk and Cotton Fabrics. Journal of Natural Fibers, Taylor & Francis. https://doi.org/10.1080/15440478.2022.2081281

Klimiuk, E., Filipkowska, U., and Korzeniowska, A. (1999). Effects of pH and Coagulant Dosage on Effectiveness of Coagulation of Reactive Dyes from Model Wastewater by Polyaluminium Chloride (PAC). Polish Journal of Environmental Studies, 8(2): 73–79.

Krans, N.A., Van Uunen, D.L., Versluis, C., Dugulan, A. ., Chai, J., Hofmann, J.P., Hensen, E.J.M., Zečević, J., and De Jong, K.P. (2020). Stability of Colloidal Iron Oxide Nanoparticles on Titania and Silica Support. Chemistry of Materials, 32(12): 5226-5235. https://doi.org/10.1021/acs.chemmater.0c01352

Kumar, P., Prasad, B., Mishra, I.M., and Chand, S. (2008). Decolorization and COD Reduction of Dyeing Wastewater from a Cotton Textile Mill Using Thermolysis and Coagulation. Journal of Hazardous Mat., 153(1-2): 635-45, doi:10.1016/j.jhazmat.2007.09.007.

Lee, J.W., Choi, S.P., Thiruvenkatachari, R., Shim, W.G., and Moon, H. (2006). Evaluation of the performance of adsorption and coagulation processes for the maximum removal of reactive dyes. Dyes and Pigments, 69(3): 196-203. doi.org/10.1016/j.dyepig.2005.03.008

Malik, P.K., and Saha, S.K. (2003). Oxidation of direct dyes with hydrogen peroxide using ferrous ion as catalyst. Separation and Purification Technology, 31(3): 241-250. https://doi.org/10.1016/S1383-5866(02)00200-9

Misau, I.M., and Yusuf, A.A. (2016). Characterization of Water Melon Seed Used as Water Treatment Coagulant. Journal of Adv. Studies in Agri., Biologi. and Env. Sci., 3(2): 22-29.

Mohamed, R.M.S.R., Nanyan, N.M., Rahman, N.A., Kutty, N.M.A., Kassim, A.H.M. (2014). Colour Removal of Reactive Dye from Textile Industrial Wastewater Using Different Types of Coagulants. Asian Journal of Applied Sciences, 2(5): 650-57, https://www.ajouronline.com/index.php/AJAS/article/view/1734.

Monira, U. and Mostafa, M.G. (2023). Leather industrial effluent and environmental concerns: a review. Sustainable Water Res. Management, 9: 181, doi.org/10.1007/s40899-023-00969-1

Mostafa, M. G. and Hoinkis, J. (2012). Nanoparticles Adsorbent for Arsenic Removal from Drinking Water: A Review. International Journal of Environmental Science, Management and Engineering Research, 1(1): 20-31(India). http://www.ijesmer.com

Mostafa, M.G., Chen, Y.H., Jean, J.S., Liu, C.C. and Lee, Y.C. (2011). Kinetics and mechanism of arsenate removal by nanosized iron oxide-coated perlite. Journal of Hazardous Materials, 187: 89-95. https://doi.org/10.1016/j.jhazmat.2010.12.117

Mukherjee, S. (2014). Studies on removal of organic and inorganic load from waste water using coagulation-flocculation and advanced techniques. PhD thesis, Maulana Abul Kalam Azad University of Technology, West Bengal, India. Retrieved from https:// library.wbut.ac.in/cgi-bin/koha/opacretrieve-file.pl

Nassar, N.N., Marei, N.N., Vitale, G., and Arar, L.A. (2015). Adsorptive removal of dyes from synthetic and real textile wastewater using magnetic iron oxide nanoparticles: Thermodynamic and mechanistic insights. Canadian Journal of Chemical Engineering, 93(11): 1965-1974. https://doi.org/10.1002/cjce.22315

Nassar, N.N., and Ringsred, A. (2012). Rapid adsorption of methylene blue from aqueous solutions by goethite nanoadsorbents. Environmental Engineering Science, 29(8): 790-797. https://doi.org/10.1089/ees.2011.0263

Nayl, A.E.A., Elkhashab, R.A., El Malah, T., Yakout, S.M., El-Khateeb, M.A., Ali, M.M.S., and Ali, H.M. (2017). Adsorption studies on the removal of COD and BOD from treated sewage using activated carbon prepared from date palm waste. Environmental Science and Pollution Research, 24(28): 22284-22293. https://doi.org/10.1007/S11356-017-9878-4

Nourmoradi, H., Zabihollahi, S., Pourzamani, H.R. (2015). Removal of a common textile dye, navy blue (NB), from aqueous solutions by combined process of coagulation–flocculation followed by adsorption. Desalination and Water Treatment, 57(11): 5200-5211. https://doi.org/10.1080/19443994.2014.1003102

Ntuli, F., Kuipa, P.K., Muzenda, E. (2011). Designing of sampling programmes for industrial effluent monitoring. Environmental Science and Pollution Research, 18(3): 479-484. https://doi.org/10.1007/s11356-010-0395-y

Nure, J.F., Shibeshi, N.T., Asfaw, S.L., Audenaer, W., and Hulle, S.W.V. (2017). COD and colour removal from molasses spent wash using activated carbon produced from bagasse fly ash of matahara sugar factory, Oromiya region, Ethiopia. Water SA, 43(3): 470-479. https://doi.org/10.4314/wsa.v43i3.12

Papić, S., Koprivanac, N., Lončarić Božić, A., and Meteš, A. (2004). Removal of some reactive dyes from synthetic wastewater by combined Al(III) coagulation/carbon adsorption process. Dyes and Pigments, 62(3): 291–298. https://doi.org/10.1016/S0143-7208(03)00148-7

Patabandige, D.S.B.T., Wadumethrige, S.H., and Wanniarachchi, S. (2020). Decolorization and Cod Removal from Synthetic and Real Textile Dye Bath Wastewater Containing Reactive Black 5. Desalination and Water Treatment, 197: 392-401, doi:10.5004/dwt.2020.25954.

Patel, H., and Vashi, R.T. (2010). Treatment of Textile Wastewater by Adsorption and Coagulation. E-Journal of Chemistry, 7(4): 1468-1476.

Patel, H., and Vashi, R.T. (2015). Use of Naturally Prepared Coagulants for the Treatment of Wastewater from Dyeing Mills. In Characterization and Treatment of Textile Wastewater. Butterworth Heinemann, Elsevier, 225 Wyman Street, Waltham, MA 02451, USA. https://doi.org/10.1016/b978-0-12-802326-6.00006-x

Pathania, D., Sharma, S., and Singh, P. (2017). Removal of methylene blue by adsorption onto activated carbon developed from Ficus carica bast. Arabian Journal of Chemistry, 10(1): S1445-S1451. https://doi.org/10.1016/j.arabjc.2013.04.021

Patil, M.R., and Shrivastava, V.S. (2015). Adsorption removal of carcinogenic acid violet19 dye from aqueous solution by polyaniline-Fe2O3 magnetic nano-composite. Journal of Materials and Environmental Science, 6(1): 11-21.

Perng, Y.S., and Bui, H.-M. (2014). Decolorization of reactive dyeing wastewater by ferrous ammonium sulfate hexahydrate. J. of Vetnamese Env., 5(1): 27-31. doi.org/10.13141/JVE

Qasim, W., and Mane, A.V. (2013). Characterization and treatment of selected food industrial effluents by coagulation and adsorption techniques. Water Resources and Industry, 4: 1-12. https://doi.org/10.1016/j.wri.2013.09.005

Rahim, M.A., and Mostafa, M.G. (2021). Impact of Sugar Mills Effluent on Environment around Mills Area, AIMS Environmental Science, 8(1): 86-99. doi: 10.3934/environsci.2021006

Rahman, A., Kishimoto, N., Urabe, T. (2015). Adsorption Characteristics of Clay Adsorbents - Sepiolite, Kaolin and Synthetic Talc-for Removal of Reactive Yellow 138:1. Water and Environment Journal, 29(3): 375-82, doi:10.1111/wej.12131.

Rahman, A., Urabe, T., Kishimoto, N. (2013). Color Removal of Reactive Procion Dyes by Clay Adsorbents. Procedia Env. Sci., 17: 270-78, doi:10.1016/j.proenv.2013.02.038.

Rafatullah, M., Sulaiman, O., Hashim, R., and Ahmad, A. (2010). Adsorption of methylene blue on low-cost adsorbents: A review. Journal of Hazardous Materials, 177(1-3): 70-80. https://doi.org/10.1016/j.jhazmat.2009.12.047

Rodrigues, C.S.D., Madeira, L.M., and Boaventura, R.A.R. (2013). Treatment of textile dye wastewaters using ferrous sulphate in a chemical coagulation/flocculation process.

Environmental Technology, 34(6): 719-729. https://doi.org/10.1080/09593330.2012.715679

Saha, M.K., Ara, R., Kadir, S.D., and Mostafa, M.G. (2021). Environmental Vulnerability of people to Brick Kiln Hazards. SPC Journal of Env. Sci., 3(1): 23-31. doi: 10.14419/jes.v3i1.31609

Salleh, M.A.M., Mahmoud, D.K., Karim, W.A.W.A., and Idris, A. (2011). Cationic and Anionic Dye Adsorption by Agricultural Solid Wastes: A Comprehensive Review. Desalination, 280(1-3), 1-13, doi:10.1016/j.desal.2011.07.019

Salvador, M., Gutiérrez, G., Noriega, S., Moyano, A., Blanco-López, M.C., and Matos, M. (2021). Microemulsion synthesis of superparamagnetic nanoparticles for bioapplications. Int. Journal of Molecular Sciences, 22(1): 1-17. https://doi.org/10.3390/ijms22010427

Sayed, M.A. and Mostafa, M.G. (2023). Characterization of Textile Dyeing Effluent and Removal Efficiency Assessment of Al2(SO4)3 Coagulant. Asian Journal of Applied Science and Technology (AJAST), 7(3): 195-212. DOI: https://doi.org/10.38177/ajast.2023.7314

Sayed, M.A., and Mostafa, M.G. (2021). Efficiency Assessment of FeSO4 Coagulant on Yarn Dyeing Industrial Effluent. BAUET JOURNAL, 3(1), 50-58. https://journal.bauet.ac.bd/wp-content/uploads/2021/12/Art-6-.pdf.

Shakil, M.S.Z., and Mostafa, M.G. (2021). Water Quality Assessment of Paper Mills Effluent Discharge Areas. Al-Nahrain Journal of Science, 24 (3): 63-72.

Slama, H.B., Bouket, A.C., Pourhassan, Z., Alenezi, F.N., Silini, A., Cherif-Silini, H., Oszako, T., Luptakova, L., Golińska, P., and Belbahri, L. (2021). Diversity of Synthetic Dyes from Textile Industries, Discharge Impacts and Treatment Methods. Applied Sciences (Switzerland), 11(14): 1-21. https://doi.org/10.3390/app11146255

Suman, A., Ahmad, T., and Ahmad, K. (2018). Dairy wastewater treatment using water treatment sludge as coagulant: a novel treatment approach. Environment, Development and Sustainability, 20(4): 1615-1625. https://doi.org/10.1007/s10668-017-9956-2

Tareque, M.H., Islam, M.A., and Mostafa, M.G. (2023). Photocatalytic decomposition of textile dyeing effluents using TiO2, ZnO, and Fe2O3 catalysts. Nep J Environ Sci, 10(2): 49-58. https://doi.org/10.3126/njes.v10i2.46704

Unni, M., Uhl, A.M., Savliwala, S., Savitzky, B.H., Dhavalikar, R., Garraud, N., Arnold, D.P., Kourkoutis, L.F., Andrew, J.S., and Rinaldi, C. (2017). Thermal Decomposition Synthesis of Iron Oxide Nanoparticles with Diminished Magnetic Dead Layer by Controlled Addition of Oxygen. ACS Nano, 11(2): 2284-2303. https://doi.org/10.1021/acsnano.7b00609

Wasti, A., and Awan, M.A. (2016). Adsorption of textile dye onto modified immobilized activated alumina. Journal of the Association of Arab Universities for Basic and Applied Sciences, 20: 26-31. https://doi.org/10.1016/j.jaubas.2014.10.001

Wijannarong, S., Aroonsrimorakot, S., Thavipoke, P., Kumsopa, A., and Sangjan, S. (2013). Removal of Reactive Dyes from Textile Dyeing Industrial Effluent by Ozonation Process. APCBEE Procedia, 5: 279-282. https://doi.org/10.1016/j.apcbee.2013.05.048

Wojnárovits, L., and Takács, E. (2008). Irradiation treatment of azo dye containing wastewater: An overview. Radiation Physics and Chemistry, 77(3): 225-244. https://doi.org/10.1016/j.radphyschem.2007.05.003

Wong, P.W., Teng, T.T., and Norulaini, N.A.R.N. (2007). Efficiency of the coagulation-flocculation method for the treatment of dye mixtures containing disperse and reactive dye. Water Quality Research Journal of Canada, 42(1): 54-62. https://doi.org/10.2166/wqrj.2007.008

Xu, W., Gao, B., Yue, Q., Wang, Y. (2010). Effect of shear force

and solution pH on flocs breakage and re-growth formed by nano-Al13 polymer. Water Research, 44(6): 1893-1899. https://doi.org/10.1016/j.watres.2009.11.029

Zahedi, M., Shakerian, A., Rahimi, E., and Sharafati C.R. (2020). Determination of Synthetic Dyes in Various Food Samples of Iran's Market and their Risk Assessment of Daily Intake. Egyptian J. of Veterinary Sci., 51(1): 23-33. https://doi.org/10.21608/ejvs.2019.16590.1095

Zobayer, B.M.M., Mahmudul, H.M., Kaniz, F., Islam, M.M.S., Rahman, K.M., and Akhtarul, I.M. (2013). Treatment of Textile Effluent of Fokir Knitwear in Bangladesh Using Coagulation-Flocculation and Adsorption Methods. International Research Journal of Environmental Sciences, 2(6): 49-53.

Zorpas, A.A., Voukallib, I., Loizia, P. (2012). Chemical Treatment of Polluted Waste Using Different Coagulants. Desalination and Water Treatment, 45(1-3): 291-96, doi:10.1080/19443994.2012.692043