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Textile Industrial Wastewater Treatment by Polyacrylamide Aided Magnesium Chloride Hybrid Coagulant

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ABSTRACT

Textile industry is one of the major industries that pose environmental concern, whereby the wastewater produced by it is characterized with high temperature, pH, colour and COD. A hybrid coagulant which is consisting of polyacrylamide aided magnesium chloride was applied in treating textile industrial wastewater. Four independent factors, i.e. pH, dosage, agitation speed and time were used to determine their effects on colour removal (%) and COD reduction (%). All independent factors were proved to have significant effect on the colour removal and COD reduction. The optimal operating parameters were fixed at pH = 12.00, dosage = 1000 mg/L, agitation speed = 100 rpm and agitation time = 5 minutes, in attaining colour removal and COD reduction of 82.83% and 26.38%, respectively. Secondary treatment is needed to reduce COD of the textile industry wastewater to ensure that the effluent is safe to be discharged into the environment.

INTRODUCTION

Textile industry is one of the industries that pose environmental concern, whereby it demands high volume of water supply and produces high volume of wastewater. The wastewater produced by the textile industry is characterized by high temperature, pH and alkalinity (Gao et al. 2007a). In addition, high concentrations of organic matter, non-biodegradable matter, toxic substances, detergents, soap, oil & grease, sulphide as well as suspended and dissolved solids in textile industrial wastewater make it highly toxic to the environment and organisms (Noppakundilograt et al. 2010). Thus, textile wastewater needs to be properly treated before being discharged as effluent into the environment.

Coagulation-flocculation is used as a primary process in wastewater treatment and sludge dewatering (Lee et al. 2010, Lee et al. 2011a, Zou et al. 2011). Coagulation-flocculation can be explained by Derjaguin-Landau-Verwey-Overbeen theory, whereby coagulation is defined as a process that overcomes the inter-particle repulsive energy barrier and induces the aggregation of dissolved and colloidal substances. Typically, by introducing aluminium and iron salts, it is able to neutralize the surface charge of suspended particles as well as facilitate particle aggregation and finally settling under gravity. Flocculation can be explained as the bridging of aggregated flocs to form larger agglomerates in the presence of polymeric materials (Addai-Mensah & Prestidge 2005, Somasundaran et al. 2005, Natalia & Olli 2006).

However, two stage coagulation-flocculation process is often time and material consuming for those industries that are dealing with high volume of wastewater like textile industry. Thus, researchers have discovered that hybrid coagulant that consists of a mixture of materials, performs better compared to their respective individual components due to the synergistic effect of the components in hybrid coagulant (Lee et al. 2012). Various hybrid coagulants have been developed in recent years for the coagulation-flocculation purpose. Among them, polyacrylamide and polydimethyl diallylammonium chloride are often been chosen as an aid in producing hybrid coagulant, whereby polyacrylamide and polydimethyl diallylammonium chloride share the common characteristics, which are, high molecular weight and soluble in water (Yang et al. 2004, Gao et al. 2007a). With the introduction of functional components into the hybrid coagulant, the bridging mechanism can be enhanced and eventually improve the aggregating capacity (Moussas & Zouboulis 2009).

In this study, magnesium chloride was selected to be coupled with polyacryalmide to form hybrid coagulant due to its less toxicity to the environment compared to aluminium and iron salts. Magnesium has a high ionic potential (3.08 e/Å) which is anticipated to have a strong effect in coagulation (Ozkan & Yekeler 2004, Golob et al. 2005, Gao et al. 2007b, Lee et al. 2014). This polyacrylamide aided magnesium chloride hybrid coagulant was applied in the coagulation-flocculation process of textile industrial wastewater treatment. A total of four independent factors, e.g. pH, dosage, agitation speed and time were taken into account to determine their effects as well as to optimize the treatment efficiency.

MATERIALS AND METHODS

Materials: Acrylamide (AM) (>99% purity, Merck) was used as received. Ammonium persulphate (AR, Systerm) and sodium bisulphite (GR, Acros Organics) were used as redox initiators. Magnesium chloride (>99%, Bendosen) was used as received. Deioinized water was used in the preparation of polyacrylamide aided magnesium chloride hybrid coagulant.

Preparation of polyacrylamide aided magnesium chloride hybrid coagulant: The preparation of polyacrylamide aided magnesium chloride hybrid coagulant which consists of magnesium chloride and polyacrylamide has been described in Lee et al. (2011b). Aqueous solution of polyacrylamide aided magnesium chloride hybrid coagulant was prepared with a concentration of 20 g/L using 90% of magnesium chloride and 10% of polyacrylamide (weight: weight) through physical blending. The aqueous solution of polyacrylamide aided magnesium chloride hybrid coagulant was allowed to age for 24 hours at room temperature prior to any application.

Coagulation-flocculation of textile industrial wastewater: Prior to any experiment, the pH of the textile industry wastewater was adjusted by adding acid and alkali. Coagulation-flocculation process was carried out using a standard jar test (Velp Scienticia, JLT 6). Desired dosage of polyacrylamide aided magnesium chloride hybrid coagulant was introduced into the textile industrial wastewater and agitated with speed and time according to the design of experiment. Flocs formed were allowed to settle for 30 minutes and the colour and COD in the supernatant were measured using a spectrophotometer (HACH, DR2800).

Design of experiment: A 2^4 full factorial design was used to investigate the effect of the independent factors such as pH, dosage, agitation speed and time. The experiment was designed based on the levels of independent factors listed in Table 1.

To optimize textile industrial wastewater treatment, the 2^4 full factorial design was augmented to a central composite design (CCD). The central composite design was based on the levels of independent factors listed in Table 2. A second order model featuring a curvature was fitted using the equation 1:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1, i<j}^{k-1} \sum_{j=2}^{k} \beta_{ij} x_i x_j \quad ...(1)$$

Where, Y is the predicted response, the β_o offset term, β_i the linear effect, β_{ii} the squared effect and β_{ij} represents the interaction effect. Coded variables were converted to natural variables according to the following relationship (Montgomery 2001):

$$x_k = \frac{\xi_k - x_0}{\delta x} \quad ...(2)$$

Where, x_k is the coded value of the kth independent variable, ξ_k the natural variable of the kth independent variable, x_0 the natural value of the kth independent factor at the centre point, and δx is the value of step change.

The outputs of the experimental design were analysed using Minitab 14 statistical software to evaluate the effects as well as the statistical parameters. The response was ana-

Table 1: Levels of factors used in 2^4 full factorial design for textile industrial wastewater treatment.

Factors	Range and levels		
	-1	0	1
x_1: pH	11.5	12.0	12.5
x_2: dosage (mg/L)	500	750	1000
x_3: agitation speed (rpm)	75	100	125
x_4: agitation time (min)	3	5	7

Table 2: Levels of factors used in central composite design for textile industrial wastewater treatment.

Factors	Range and levels				
	-α	-1	0	1	+α
x_1: pH	11.0	11.5	12.0	12.5	13.0
x_2: dosage (mg/L)	250	500	750	1000	1250
x_3: agitation speed (rpm)	50	75	100	125	150
x_4: agitation time (min)	1	3	5	7	9

Table 3: Characteristics of textile industrial wastewater.

Parameters	Values
Temperature (°C)	44.2-46.5
pH	11.01-11.03
Conductivity (μS.cm)	1919-1967
TDS (mg/L)	962-987
Colour Point (PtCo)	810-850
COD (mg/L)	762-784
Turbidity (NTU)	24.9-26.2

lysed using ANOVA based on the p-value with 95% of confidence level.

RESULTS AND DISCUSSION

Textile industrial wastewater characteristics: The textile industrial wastewater sample was collected from a textile factory in Malaysia. The characteristics of textile industrial wastewater are given in Table 3. The dyes used in the fabric dyeing process were reactive dye, vat dye and disperse dye. Reactive dye and vat dye are generally used to colour cotton fabric; whereas, disperse dye is used to dye polyester fabric. To dye the fabric, reactive dye, vat dye and disperse dye are applied in dye baths with the temperatures of 130°C, 60°C and 90°C, respectively. The wastewater sample collected was a mix from the dye baths. The temperature of the wastewater collected at the sampling point was relatively high (44.2°C) compared to the ambient temperature. To fix colour on the fabric, the dye bath water is usually controlled at a high pH (Golob et al. 2005). Thus, the pH of the wastewater sample was found to be relatively high (pH ~ 11). Other chemicals and auxiliaries are added into the dye baths which produce wastewater with high conductivity, TDS, colour point and COD (Reedy et al. 2008). The wastewater produced, therefore, should be treated before being discharged into the environment. In view of the high pH of textile industrial wastewater sample, polyacrylamide aided magnesium chloride hybrid coagulant is used for the treatment due to its suitability in treating wastewater with high pH.

Screening of independent factors: To determine the significance of independent factors for textile industrial wastewater treatment, a 2^4 full factorial design was carried out to screen the factors that affect the efficiency of textile industrial wastewater treatment. Four factors, i.e. pH, dosage, agitation speed and time were taken into account in the factorial design. A total of 20 experimental runs are required, which consist of 16 factorial runs and 4 centre points as indicated in Table 4. Colour removal (%) and COD reduction (%) are taken as the response.

The normal probability plots of the standardized effects of colour removal and COD reduction of textile industrial wastewater using polyacrylamide aided magnesium chloride hybrid coagulant are shown in Figs. 1 and 2, respectively. All independent factors show significant effect on the colour removal (%) and COD reduction (%). The order of significant independent factors for colour removal (%) is: dosage > pH > agitation speed > agitation time. Meanwhile, the order of significant independent factors for COD reduction (%) is: pH > dosage > agitation time > agitation speed. Interaction effect of pH*dosage is the most significant interaction factor in affecting colour removal and COD reduction. For colour removal, two-way interaction factors that associate with pH, dosage, agitation speed and agitation time are found to be significant except for the interaction factor of agitation speed*agitation time. However, all interaction factors that associate with agitation speed and time are found to be insignificant in affecting COD reduction (%).

The main effect plots for colour removal (%) and COD reduction (%) of textile industrial wastewater are shown in Figs. 3 and 4, respectively. The slope associated with centre point denotes the relative strength of the factor. It is noted that a relatively higher performance is achieved at the centre points of the factors for colour removal. The colour removal increases with the pH from 11.5 to 12.0 and dosage from 500 to 750 mg/L. The colour removal decreases with the further increase of pH and dosage, which is consistent with the findings of Gao et al. (2007b). Moderate agitation speed and times are sufficient to give high performance in colour removal where a relatively higher performance is achieved at the centre points of agitation speed and time. For COD reduction, the performance increases proportionally with the level of factors. However, the main effects for agitation speed and time are relatively weak as the slopes of their main effects are relatively flat compared to that of pH and dosage. The COD reduction of textile industrial wastewater is relatively lower. This could be due to the composition of textile industrial wastewater, whereby it contains substantial chemicals and auxiliaries which are difficult to be removed (Montgomery 2001).

Table 4: 2^4 full factorial design for textile industrial wastewater treatment.

Experiments	Blocks	pH	Dosage	Speed	Time
1	1	11.5	500	75	3
2	1	12.5	500	75	3
3	1	11.5	1000	75	3
4	1	12.5	1000	75	3
5	1	11.5	500	125	3
6	1	12.5	500	125	3
7	1	11.5	1000	125	3
8	1	12.5	1000	125	3
9	1	11.5	500	75	7
10	1	12.5	500	75	7
11	1	11.5	1000	75	7
12	1	12.5	1000	75	7
13	1	11.5	500	125	7
14	1	12.5	500	125	7
15	1	11.5	1000	125	7
16	1	12.5	1000	125	7
17	1	12	750	100	5
18	1	12	750	100	5
19	1	12	750	100	5
20	1	12	750	100	5

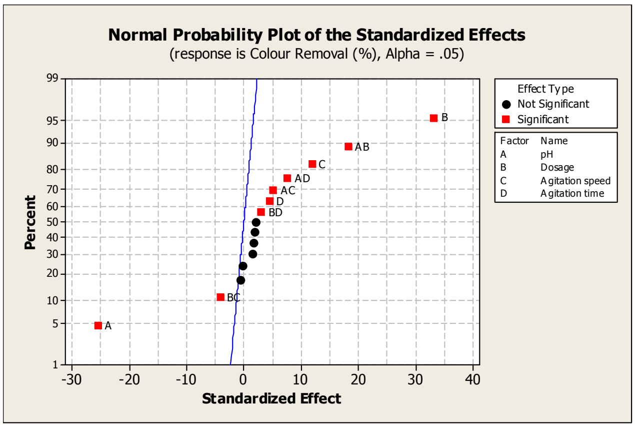

Fig. 1: Normal probability plot of standardized effect for colour removal (%).

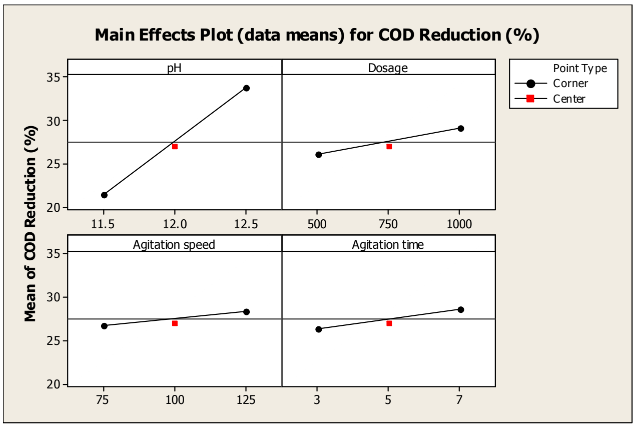

Fig. 4: Main effects plot on COD reduction (%) of textile industrial wastewater treatment.

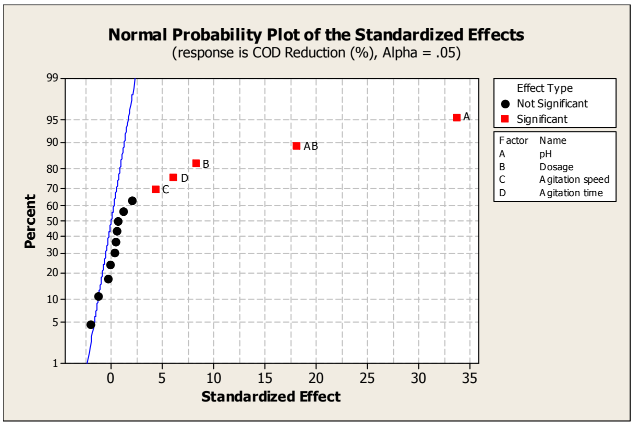

Fig. 2: Normal probability plot of standardized effect for COD reduction (%).

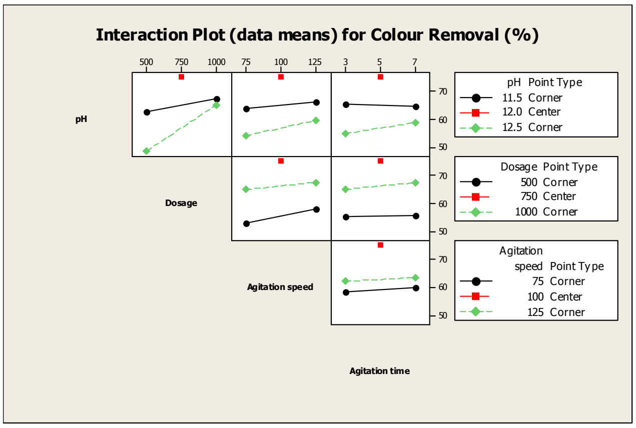

Fig. 5: Interaction effects plot on colour removal (%) of textile industrial wastewater treatment.

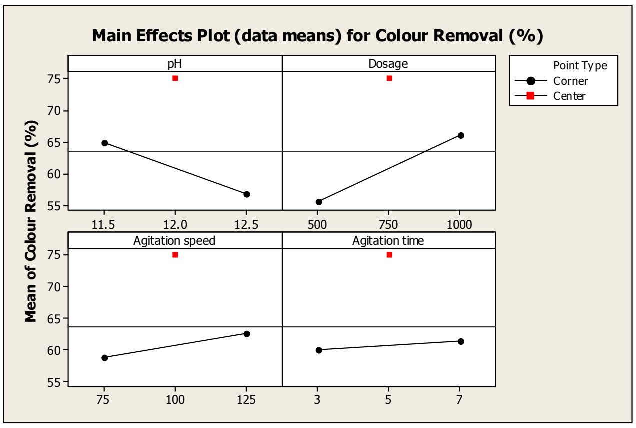

Fig. 3: Main effects plot on colour removal (%) of textile industrial wastewater treatment.

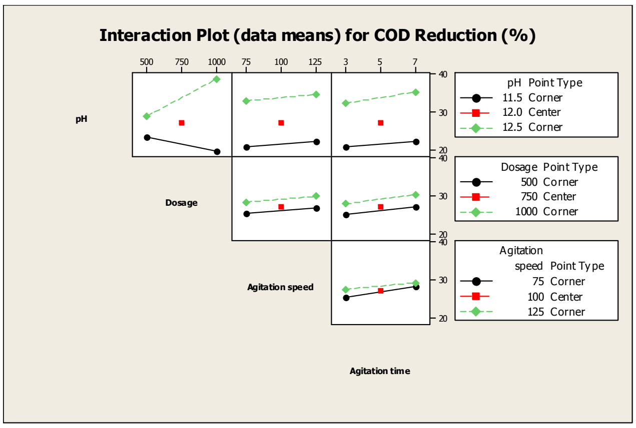

Fig. 6: Interaction effects plot on COD reduction (%) of textile industrial wastewater treatment.

Table 5: ANOVA analysis for colour removal (%) of textile industrial wastewater treatment.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	2	38.10	38.10	19.05	2.53	0.090
Main effects	2	2139.76	2139.76	1069.88	141.82	0.000
2-way Interactions	1	403.85	403.85	403.85	53.53	0.000
Curvature	1	1941.03	1941.03	1941.03	257.30	0.000
Residual Error	53	399.82	399.82	7.54		
Lack of Fit	8	14.37	14.37	1.80	0.21	0.988
Pure Error	45	385.45	385.45	8.57		
Total	59					

Table 6: ANOVA analysis for COD reduction (%) of textile industrial wastewater treatment.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	2	40.53	40.53	20.267	12.03	0.000
Main effects	4	2040.47	2040.47	510.117	302.89	0.000
2-way Interactions	1	531.27	531.27	531.269	315.45	0.000
Curvature	1	3.47	3.47	3.473	2.06	0.157
Residual Error	51	85.89	85.89	1.684		
Lack of Fit	42	71.50	71.50	1.702	1.06	0.498
Pure Error	9	14.40	14.40	1.600		
Total	59	2701.64				

The interaction plots (data means) for colour removal (%) and COD reduction (%) of textile industrial wastewater are shown in Figs. 5 and 6, respectively. The interaction effect of pH*dosage is the most significant interaction factor in affecting colour removal and COD reduction where the plots are observed to be significantly unparallel. In the interaction plots of colour removal (%), interaction effect that associate with pH, dosage, agitation speed and time are found to be unparallel, except the interaction plots of agitation speed*agitation time, denotes their insignificance. For COD reduction (%), all interaction plots that associate with agitation speed and time are parallel which imply the insignificance of the interactions.

ANOVA analysis was used to determine the statistical significance of colour removal and COD reduction in treating textile industrial wastewater using polyacrylamide aided magnesium chloride hybrid coagulant. The statistical significance was determined at the level of significance at 5 % probability level in which p-value < 0.05. The ANOVA analysis for colour removal (%) and COD reduction (%) for textile industrial wastewater are presented in Tables 5 and 6, respectively. The main effects, 2-way interactions as well as curvature for colour removal are found to be significant. This implies that the remarkable colour removal observed at the centre points for all factors are the locations of the optimal condition. For COD reduction (%), the main effects and 2-way interactions are found to be significant. Therefore, a reduced model was fitted for colour removal and COD reduction during the optimization study.

Optimization textile industrial wastewater treatment: A central composite design was constructed by augmenting factorial design through the addition axial points. The central composite design as given in Table 7 consists of 16 factorial runs (Experiment 1-16), 4 factorial centre points (Experiment 17-20), 8 axial points (Experiment 21-28) and 2 axial centre points (Experiment 29-30). The optimization experiments were conducted randomly in triplicate to minimize the effects of the uncontrolled factors.

The estimated regression coefficients of all terms of the regression models for colour removal and COD reduction, which comprise coefficient, standard error of coefficient, *t*-statistics as well as p-value are given in Tables 8 and 9, respectively. To fit a reduced model for colour removal (%), variable terms, such as A, B, A^2, B^2 and AB were taken into account for second-order model which are expressed as:

$$\text{Colour removal (\%)} = 76.3746 - 2.6815A + 5.9807B - 9.1207A^2 - 2.8316B^2 + 2.9006AB \quad ...(3)$$

For COD reduction (%), a reduced model in which consists of variable terms, such as A, B, C, D, A^2, B^2, C^2, D^2 and AB to be fitted in a second-order model is expressed as:

$$\text{COD reduction (\%)} = 26.8546 + 6.6571A + 1.1885B + 0.6485C + 0.7904D - 0.5807A^2 - 0.7907B^2 + 0.8214C^2 + 0.6547D^2 + 3.3269AB \quad ...(4)$$

Table 7: Central composite design matrix for textile industrial wastewater treatment.

Experiments	Blocks	pH	Dosage	Speed	Time
1	1	11.5	500	75	3
2	1	12.5	500	75	3
3	1	11.5	1000	75	3
4	1	12.5	1000	75	3
5	1	11.5	500	125	3
6	1	12.5	500	125	3
7	1	11.5	1000	125	3
8	1	12.5	1000	125	3
9	1	11.5	500	75	7
10	1	12.5	500	75	7
11	1	11.5	1000	75	7
12	1	12.5	1000	75	7
13	1	11.5	500	125	7
14	1	12.5	500	125	7
15	1	11.5	1000	125	7
16	1	12.5	1000	125	7
17	1	12	750	100	5
18	1	12	750	100	5
19	1	12	750	100	5
20	1	12	750	100	5
21	2	11	750	100	5
22	2	13	750	100	5
23	2	12	250	100	5
24	2	12	1250	100	5
25	2	12	750	50	5
26	2	12	750	150	5
27	2	12	750	100	1
28	2	12	750	100	9
29	2	12	750	100	5
30	2	12	750	100	5

Table 8: Estimated regression coefficients for colour removal (%) of textile industrial wastewater treatment.

Term	Coef	SE Coef	T	P
Constant	76.3746	0.8458	90.297	0.000
Block 1	-5.1254	0.7588	-6.754	0.000
Block 2	4.4711	0.9973	4.483	0.000
Block 3	-4.8584	0.7588	-6.403	0.000
Block 4	4.7891	0.9973	4.802	0.000
Block 5	-3.3174	0.7588	-4.372	0.000
A	-2.6815	0.4177	-6.419	0.000
B	5.9807	0.4177	14.317	0.000
C	1.5226	0.4177	3.645	0.001
D	0.5382	0.4177	1.288	0.202
A^2	-9.1207	0.3907	-23.342	0.000
B^2	-2.8316	0.3907	-7.247	0.000
C^2	0.6376	0.3907	1.632	0.107
D^2	0.8776	0.3907	2.246	0.028
AB	2.9006	0.5116	5.670	0.000
AC	0.8202	0.5116	1.603	0.113
AD	1.2210	0.5116	2.387	0.020
BC	-0.6565	0.5116	-1.283	0.204
BD	0.4919	0.5116	0.961	0.340
CD	-0.0419	0.5116	-0.082	0.935

*A: pH; B: Dosage; C: Agitation speed; D: Agitation time

Table 9: Estimated regression coefficients for COD reduction (%) of textile industrial wastewater treatment.

Term	Coef	SE Coef	T	P
Constant	26.8546	0.3622	74.145	0.000
Block 1	1.6677	0.3249	5.133	0.000
Block 2	-0.0313	0.4271	-0.073	0.942
Block 3	0.1743	0.3249	0.536	0.593
Block 4	-0.1952	0.4271	-0.457	0.649
Block 5	-0.2483	0.3249	-0.764	0.447
A	6.6571	0.1789	37.217	0.000
B	1.1885	0.1789	6.644	0.000
C	0.6485	0.1789	3.625	0.001
D	0.7904	0.1789	4.419	0.000
A^2	-0.5807	0.1673	-3.471	0.001
B^2	-0.7907	0.1673	-4.726	0.000
C^2	0.8214	0.1673	4.909	0.000
D^2	0.6547	0.1673	3.913	0.000
AB	3.3269	0.2191	15.186	0.000
AC	0.0481	0.2191	0.220	0.827
AD	0.3635	0.2191	1.659	0.101
BC	-0.0223	0.2191	-0.102	0.919
BD	0.0848	0.2191	0.387	0.700
CD	-0.2465	0.2191	-1.125	0.264

*A: pH; B: Dosage; C: Agitation speed; D: Agitation time

Where, A = pH; B : Dosage; C = Agitation speed; D = Agitation time.

The reduced second-order models with respective variable terms represent the effect of a particular factor, while those with two variables second-order term represents the interaction term between two variables and quadratic effect, respectively.

Tables 10 and 11 show the corresponding ANOVA tables for the reduced models of colour removal and COD reduction of textile industrial wastewater, respectively. The p-values for linear, square and interaction terms of colour removal and COD reduction are smaller than 0.05 which denotes the significance of the terms. The lack-of-fit tests for colour removal and COD reduction are insignificant ($p>0.05$) implying that the fitted models are adequate in predicting colour removal and COD reduction. The coefficients of determination (R^2) of colour removal (%) and COD reduction (%) are 90.9% and 96.1%, respectively; which implies that the sample variable of 90.9% and 96.1% for colour removal (%) and COD reduction (%) are attributed to the regressors in the models, respectively (Montgomery 2001).

To validate and to determine the adequacy of regression models of colour removal and COD reduction to the experimental data, diagnostic plots that compare predicted data with experimental data were plotted. Comparison of predicted and experimental data for colour removal and COD reduction are shown in Figs. 7 and 8 with R^2 values of 0.9533

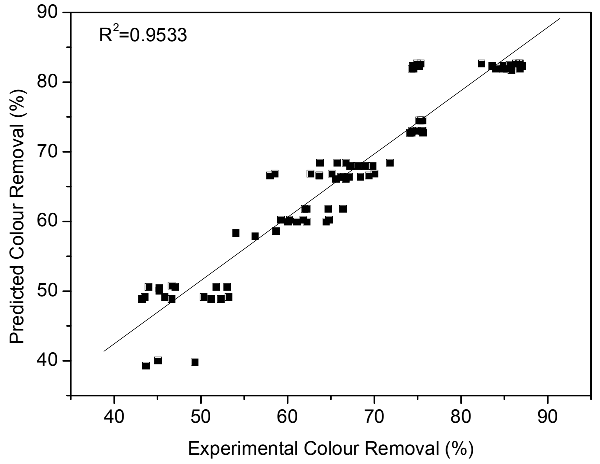

Fig. 7: Plot of predicted vs experimental colour removal (%) of textile industrial wastewater treatment.

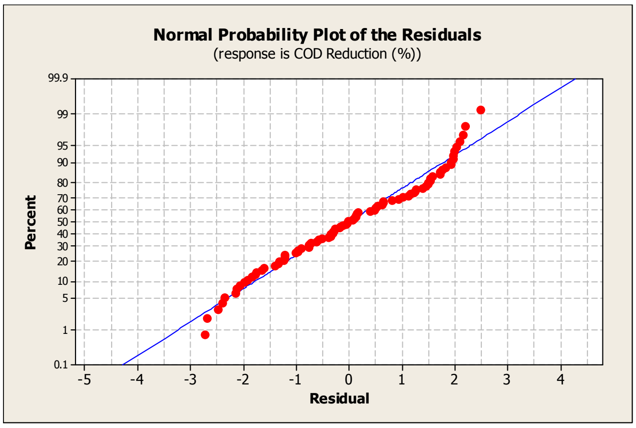

Fig. 10: Normal probability plot of the residuals for COD reduction (%) of textile industrial wastewater treatment.

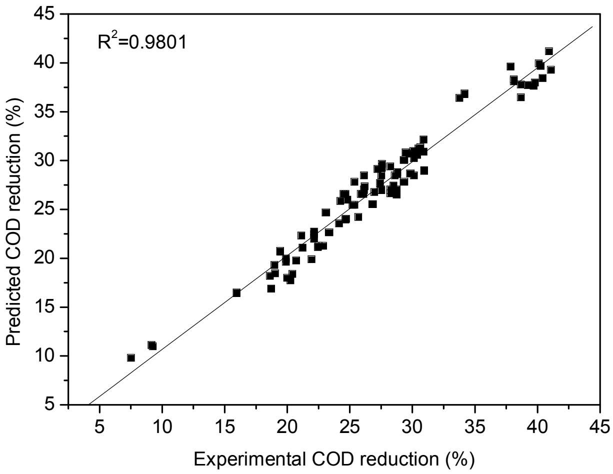

Fig. 8: Plot of predicted vs experimental COD reduction (%) of textile industrial wastewater treatment.

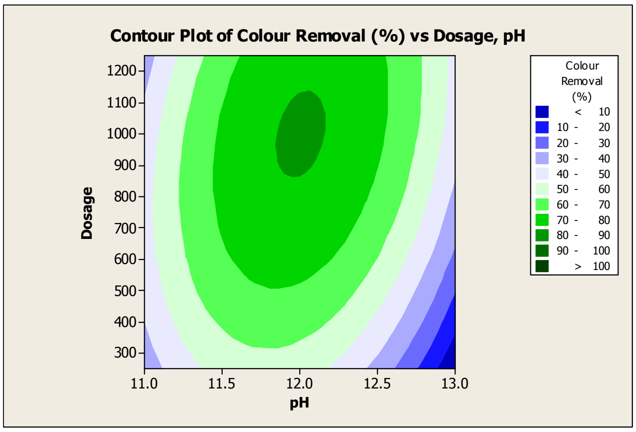

Fig. 11: Two-dimensional response contour plots of colour removal (%) of textile industrial wastewater treatment.

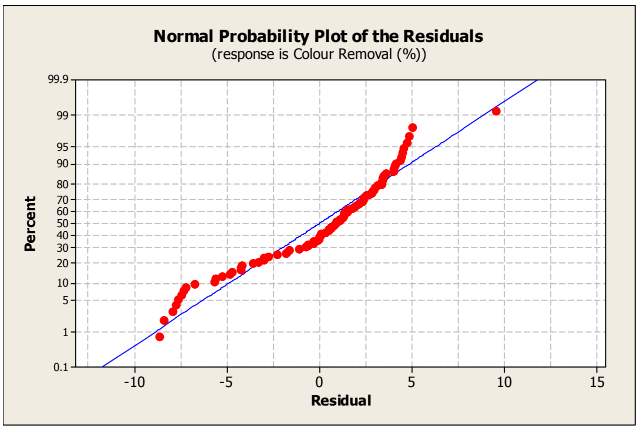

Fig. 9: Normal probability plot of the residuals for colour removal (%) of textile industrial wastewater treatment.

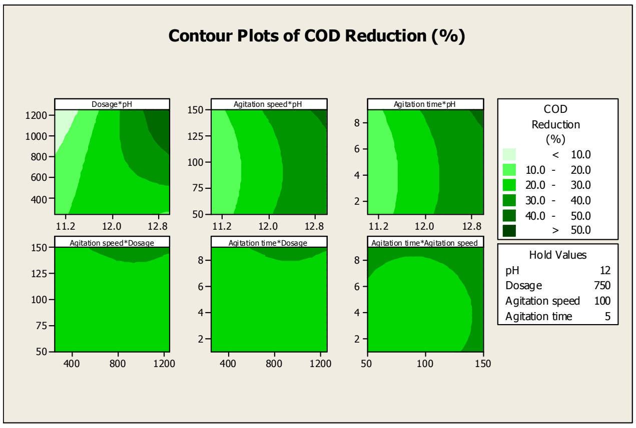

Fig. 12: Two-dimensional response contour plots of COD reduction (%) of textile industrial wastewater treatment.

Table 10: ANOVA analysis for colour removal (%) of textile industrial wastewater treatment.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	5	1613.6	1613.6	322.71	19.78	0.000
Regression	5	11234.4	11234.4	2246.89	137.72	0.000
Linear	2	3093.1	3093.1	1546.53	94.79	0.000
Square	2	7737.5	7737.5	3868.76	237.13	0.000
Interaction	1	403.9	403.9	403.85	24.75	0.000
Residual Error	79	1288.9	1288.9	16.31		
Lack of Fit	19	429.9	429.9	22.63	1.58	0.092
Pure Error	60	859.0	859.0	14.32		
Total	89	14136.9				

S = 4.039 R^2 = 90.9% R^2 (adj) = 89.7%

Table 11: ANOVA analysis for COD reduction (%) of textile industrial wastewater treatment.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	5	73.73	73.73	14.746	6.47	0.000
Regression	9	4097.24	4097.24	455.249	199.67	0.000
Linear	4	3367.76	3367.76	841.941	369.28	0.000
Square	4	198.21	198.21	49.551	21.73	0.000
Interaction	1	531.27	531.27	531.269	233.02	0.000
Residual Error	75	171.00	171.00	2.280		
Lack of Fit	63	155.49	155.49	2.468	1.91	0.108
Pure Error	12	15.50	15.50	1.292		
Total	89	4341.96				

S = 1.510 R^2 = 96.1% R^2 (adj) = 95.3%

Table 12: Optimal conditions and model validation for textile industrial wastewater treatment.

Factors pH	Dosage (mg/L)	Agitation speed (rpm)	Agitation time (min)	Predicted colour removal (%)	Experimental colour removal (%)	Predicted COD reduction (%)	Experimental COD reduction (%)
12.00	1000	100	5	80.85	82.83	27.25	26.38

and 0.9801, respectively. All data points locate around a linear line implies a good fit of model to the experimental data.

The adequacy of approximation of the regression models to the real systems is determined through normal probability plots of standardized residuals. The normal probability plot of standardized residuals for the reduced models of colour removal and COD reduction is shown in Figs. 9 and 10, respectively. All points scattered along a straight line, denoting that the errors are distributed normally for the reduced models of colour removal and COD reduction of textile industrial wastewater treatment.

To visualize the optimal condition for colour removal and COD reduction, two-dimensional response contour plots for colour removal and COD reduction were plotted, as shown in Figs. 11 and 12, respectively. For colour removal, a reduced model only takes into account the pH and dosage, based on their significance in affecting the treating efficiency. The other factors are controlled at centre point (0) of the factors whereby agitation speed = 100 rpm and agitation time = 5 minutes. It is found that colour removal has a significant change with pH and dosage where the maximum colour removal is achieved at pH between 11.8 to 12.2 and dosage between 800 to 1100 mg/L. For COD reduction, factors that are associated with agitation speed and time are visually insignificant on the treatment efficiency. The maximum COD reduction is achieved at pH between 12.8 to 13.0 and dosage between 800 to 1200 mg/L.

The optimal operating parameters were determined through Minitab software and are given in Table 12 with pH = 12.00, dosage = 1000 mg/L, agitation speed = 100 rpm and agitation time = 5 minutes. To compromise in optimizing colour removal and COD reduction, the predicted

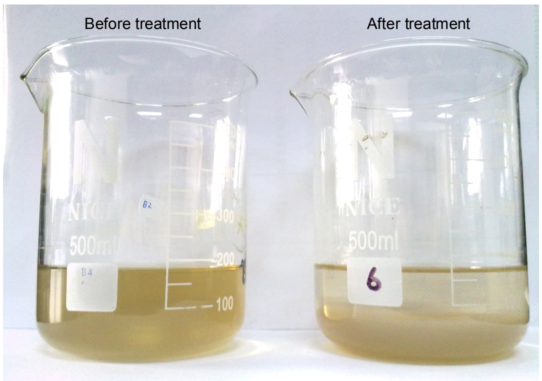

Fig. 13: Comparison of textile industrial wastewater before and after treatment.

optimal colour removal and COD reduction are 80.85% and 27.25%, respectively; the experimental colour removal and COD reduction are 82.83% and 26.38%, respectively. The small deviation between the experimental and predicted values of colour removal and COD reduction indicates that the models are sufficient to predict colour removal and COD reduction. Fig. 13 shows the comparison of textile industrial wastewater before and after treatment. It is observed that the colour of dye wastewater has been faded by using polyacrylamide aided-magnesium chloride hybrid coagulant and sludge was formed at the bottom of the beaker.

CONCLUSIONS

Polyacrylamide aided magnesium chloride hybrid coagulant was applied in treating textile industrial wastewater. Effect of four independent factors, i.e. pH, dosage, agitation speed and time were investigated. All independent factors were shown to have a significant effect on the colour removal (%) and COD reduction (%).The order of significant independent factors for colour removal is: dosage > pH > agitation speed > agitation time. Meanwhile, the order of significant independent factors for COD reduction is: pH > dosage > agitation time > agitation speed. The optimal operating parameters were fixed at pH = 12.00, dosage = 1000 mg/L, agitation speed = 100 rpm and agitation time = 5 minutes, in attaining colour removal and COD reduction of 82.83% and 26.38%, respectively. Secondary treatment is needed to reduce COD of the textile industry wastewater to ensure the effluent is safe to be discharged to the environment.

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REFERENCES

Addai-Mensah, J. and Prestidge, C.A. 2005. Structure formation in dispersed systems. In: Stechemesser, H. and Dobias, B. (eds.) Coagulation and Flocculation, 2nd ed. Taylor & Francis Group: Boca Raton, pp. 135-216.

Gao, B.Y., Wang, Y., Yue, Q.Y., Wei, J.C. and Li, Q. 2007a. Color removal from simulated dye water and actual textile wastewater using a composite coagulant prepared by ployferric chloride and polydimethyl diallylammonium chloride. Sep. Purif. Technol., 54: 157-163.

Gao, B.Y., Yue, Q.Y., Wang, Y. and Zhou, W.Z. 2007b. Color removal from dye-containing wastewater by magnesium chloride. J. Environ. Manage., 82: 167-172.

Golob, V., Vinder, A. and Simonic, M. 2005. Efficiency of the coagulation/flocculation method for the treatment of dyebath effluents. Dyes Pigments., 67: 93-97.

Lee, K.E., Teng, T.T., Morad, N., Poh, B.T. and Hong, Y.F. 2010. Flocculation of kaolin in water using novel calcium chloride-polyacrylamide ($CaCl_2$-PAM) hybrid polymer. Sep. Purif. Technol., 75: 346-351.

Lee, K.E., Teng, T.T., Morad, N., Poh, B.T. and Mahalingam, M. 2011a. Flocculation activity of novel ferric chloride-polyacrylamide ($FeCl_3$-PAM) hybrid polymer. Desalination, 266: 108-113.

Lee, K.E., Khan, I., Morad, N., Teng, T.T. and Poh, B.T. 2011b. Physicochemical and rheological properties of novel magnesium salt polyacrylamide composite polymers. J. Disper. Sci. Technol., 33: 1284-1291.

Lee, K.E., Morad, N., Teng, T.T. and Poh, B.T. 2012. Development, characterization and the application of hybrid materials in coagulant/flocculation of wastewater: A review. Chem. Eng. J., 203: 370-386.

Lee, K.E., Morad, N., Teng, T.T. and Poh, B.T. 2014. Reactive dye removal using inorganic-organic composite material: kinetics, mechanism, and optimization. J. Disper. Sci. Technol., 35: 1557-1570.

Montgomery, D.C. 2001. Design and Analysis of Experiments, 5th ed. New York: John Wiley & Sons: United States.

Moussas, P.A. and Zouboulis, A.I. 2009. A new inorganic-organic composite coagulant, consisting of polyferric sulphate (PFS) and polyacrylamide (PAA). Water Res., 43: 3511-3524.

Natalia, M. and Olli, D. 2006. Environmental implications of aggregations phenomena: current understanding. Curr. Opin. Colloid In., 11: 246-266.

Noppakundilograt, S., Nanakorn, P., Jinsart, W. and Kiatkamjornwong, S. 2010. Synthesis of acrylamide/acrylic acid-based aluminum flocculant for dye reduction and textile wastewater treatment. Polym. Eng. Sci., 50: 1535-1546.

Ozkan, A. and Yekeler, M. 2004. Coagulation and flocculation characteristics of celestite with different inorganic salts and polymers. Chem. Eng. Process, 43: 873-879.

Reedy, S.S., Kotaiah, B. and Reedy, N.S.P. 2008. Colour pollution control in textile dyeing industry effluents using tannery sludge derived activated carbon. B. Chem. Soc. Ethiopia, 22: 369-378.

Somasundaran, P., Runkana, V., Kapur, P.C. Flocculation and dispersion of colloidal suspensions by polymers and surfactants: experimental and modeling studies. In: Stechemesser, H. and Dobias, B. (eds.) Coagulation and Flocculation, 2nd ed. Taylor & Francis Group: Boca Raton, pp. 135-216.

Yang, W. Y., Qian, J. W. and Shen, Z. Q. 2004. A novel flocculant of $Al(OH)_3$-polyacrylamide ionic hybrid. J. Colloid Interf. Sci., 273: 400-405.

Zou, J., Zhu, H., Wang, F., Sui, H. and Fan, J. 2011. Preparation of a new inorganic-organic composite flocculant used in solid-liquid separation for waste drilling fluid. Chem. Eng. J., 171: 350-356.