RSC Advances



View Article Online

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PAPER



Cite this: RSC Adv., 2015, 5, 34206

Received 23rd January 2015 Accepted 7th April 2015 DOI: 10.1039/c5ra01346a

www.rsc.org/advances

1. Introduction

The potential adverse effect of dyes and pigments on the environment is global nowadays. A wide range of industries such as the paper, leather, plastics, cosmetics, food, printing and pharmaceutical industries, apply dyes for their coloration processes, but by far the dominant industry utilized dye is the textile manufacturing industry. The dyeing process is the concept to link dye molecules covalently to fiber molecules, however incomplete exhaustion of dyes onto textile fibers has become a major problem.¹ Subsequently, various pollutants such as remaining dyes, organic compounds and surfactants could be found in textile effluents.² Proper treatment is required to ensure efficient removal of the pollutants before being discharged into the environment. This is because incompletely degraded products would create toxicological and ecotoxicological issues due to their toxic, non-biodegradable and mutagenic nature. For example, benzene can imperil human being nervous and vascular systems; phenol can affect aquatic system by hindering marine plants and organisms growth.³

Therefore, various methodologies, such as electro-peroxone, photocatalytic, advanced oxidation process, aerobic and anaerobic degradation using various microorganisms,

Degradation of cationic and anionic dyes in coagulation—flocculation process using bi-functionalized silica hybrid with aluminum-ferric as auxiliary agent

Yen-Yie Lau,^a Yee-Shian Wong,^{ab} Tjoon-Tow Teng,^{*a} Norhashimah Morad,^a Mohd Rafatullah^a and Soon-An Ong^b

Cationic dye (methylene blue) and anionic dye (methyl orange) degradation in the coagulation process was demonstrated. The key material was a natural coagulant–laterite soil dominated by a silica component, while aluminum-ferric ions acted as an auxiliary agent in the degradation process. Charge neutralization, electrical double layer compression and sweeping flocculation were the mechanisms in the decolorization reaction. These results provided a new insight into effective dye degradation using a new class of natural coagulant–natural resources (laterite soil). The complex molecular structure of methylene blue and methyl orange was degraded into smaller hydrocarbon forms, accompanied by the formation of silsesquioxane. The silsesquioxane was the final product of degradation with promising flocculation and low volume sludge. Lastly, a comparison of the aluminum-based coagulant and a laterite soil natural coagulant shows a clear vision of the performance for both types of coagulant.

coagulation,⁴⁻⁹ have been employed to study the dye degradation processes. Among them, coagulation is considered as one of the most practicable processes used in industrial wastewater treatment.¹⁰ Coagulation stage is an instantaneous process occurred when a coagulant is added into the colloidal dispersion wastewater. Subsequently, it leads to rapid breakage or rearrangement and aggregation of particles. Coagulation mechanisms can be accomplished by (1) electrical double layer compression, (2) adsorption and charge neutralization, (3) enmeshment in a precipitation, and (4) adsorption and interparticle bridging.¹¹

The commonly used coagulants in industry are chemicalbased coagulants, such as aluminum sulphate (alum), ferric chloride (FeCl₃) and polyaluminum chloride (PACl). Application of these chemical substances creates several impacts, such as increase of metal concentration in water, voluminous toxic sludge produced and detrimental effects on human health. There is strong evidence linking aluminum-based coagulants to the development of Alzheimer's disease in human being.¹² Due to the disadvantages of chemical coagulants, application of ecofriendly and natural coagulant phenomena was approached in order to substitute the chemical coagulants. Various coagulants had been identified from animal and plant origins such as chitosan,13 M. oleifera, tannin and cactus14 and okra extracted from okra seeds pod tips, plant stalk and root.15 Scientific results showed that requirement of alum could be reduced 50-90 % upon replacement of okra as primary coagulant and coagulant aid. Laterite soil which is naturally available on the

^aSchool of Industrial Technology, Universiti Sains Malaysia, 11800 Minden, Pulau Pinang, Malaysia. E-mail: ttteng@usm.my; Fax: +604-657-3678; Tel: +604-6532215 ^bSchool of Environmental Engineering, Universiti Malaysia Perlis, Kompleks Pusat Pengajian Jejawi 3, 02600 Arau, Perlis, Malaysia

earth is selected as natural coagulant since it contains elements of coagulation–flocculation functions. Laterite soil is not underlying in animal and plants origin, therefore a new class of natural coagulant is established which can be named as natural resources.

In this present work, a study of dye degradation using natural coagulant (laterite soil) was undertaken. Cationic dye (methylene blue) and anionic dye (methyl orange) were selected to analyze coagulation mechanisms of laterite soil with the aid of zeta potential measurements. Meanwhile, UV-Vis, GC-MS and FT-IR analysis were used to identify the degradation intermediates and products. Properties of degradation intermediates and products were essential to ensure zero potential hazardous substances were released. The results provided effectiveness comparison on laterite soil as natural coagulant with chemical-based coagulants.

2. Methodology

2.1 Dyes

Methylene blue ($C_{16}H_{18}N_3SCl$; molecular weight 373.90 g-mol⁻¹; absorption wavelength 664.00 nm) and methyl orange ($C_{14}H_{14}$ - N_3NaO_3S ; molecular weight 327.33 g-mol⁻¹; absorption wavelength 464.50 nm) were purchased from Sigma Aldrich. Their molecular structures are shown in Fig. 1. Stock solution of dyes was prepared by dissolving 1 g of dye with deionized water using a 1 L volumetric flask. 50 mg L⁻¹ of dye solutions were prepared by diluting the stock solutions.

2.2 Characteristics of laterite soil

The morphology of laterite soil was analyzed using JEOL (Model JSM-6460LA) Analytical scanning electron microscope. Energy dispersive X-ray analysis (Model Oxford-50) was conducted for identifying the element contents in the laterite soil. Fig. 2 shows the morphology and topography of laterite soil. The characteristic of laterite soil was further analyzed by using X-ray fluorescence (XRF) to distinguish the exact element content percentage and the corresponding identified compounds are shown in Fig. 3. The major constituents of laterite soil are SiO₂ (36.30%), Al₂O₃ (27.10%) and Fe₂O₃ (26.86%) as illustrated in the Fig. 2 and 3. The components in the laterite soil could act as coagulant and flocculant in the wastewater treatment.

2.3 Preparation of laterite soil

The laterite soil was collected from Bukit Merah, Perlis, Malaysia. The raw reddish laterite soil went through the following pretreatment: it was decolorized before being used as



Fig. 1 Chemical structures of dyes: (a) methylene blue; (b) methyl orange.

coagulant to treat synthetic dye wastewater. The laterite soil was mixed with ultrapure water and subsequently the mixtures were filtered with nylon cloth to remove the impurities. The laterite soil containing filtrate was collected and left to settle until double layers were observed. The aqueous phase was drained off and the laterite soil paste was dried under the sunlight. The procedure was repeated until the laterite soil was decolorized. The dried laterite soil was crushed into powder and sieved through 75 μ m siever. The sieved laterite soil powder was mixed in ultrapure water and blended, followed by filtration to remove excessive fluid. Laterite soil paste collected on the filter paper was readily used as coagulant.

2.4 Coagulation experiments

The coagulation experiments on synthetic dye solutions were performed using Jar-Test apparatus (JLT6 VELP Scientifica). The optimum pH was obtained by fixing a coagulant dosage and varying the initial pH from 1 to 9, using dilute hydrochloric acid (HCl) or sodium hydroxide (NaOH) solution (0.01-0.1 M). The pH of each solution was measured by 827 pH lab (Methrohm). The mixtures of dye wastewater and laterite soil were stirred rapidly at 200 rpm for 2 minutes, then slowly at 100 rpm for 15 minutes. Subsequently, the mixtures were allowed to settle for 30 minutes. 20 mL of liquid was collected at 2 cm beneath the liquid in the settling beaker. The collected samples were filtered through 20-25 µm pore size Whatman filter papers and the filtrates were ready for analysis (Section 2.5). The identified optimum pH was used and the experiments were continued by varying the dosage of laterite soil coagulant. The procedures were continued as mentioned above.

2.5 Analysis

The color point (measure of dye concentration) of a dye solution was determined by using Hitachi u-2800 UV-Visible Spectrophotometer. The turbidity was determined by using Eutech TN 100 turbidity meter in Nephelometric Turbidity Unit (NTU). Zeta potential of a solution was measured by using Dispersion Technology – Acousto Phor Zeta Titration 310 method. After the optimum pH and laterite soil dosage have been determined to treat methylene blue and methyl orange, the sludge obtained at these optimum conditions were sent for sludge volume index (SVI) determination, Fourier transforms infrared spectrophotometry (FT-IR) and Thermogravimetric analysis (TGA) analyses. SVI analysis was carried out in accordance with the standard methods for the examination of water and wastewater.¹⁶ It is the volume in milliliters occupied by 1 g of a suspension after 30 min. settling. Equation used to calculate SVI is given below:

$$SVI = \frac{Settled sludge volume after 30 minutes(mL L-1) × 100}{Total suspended solids(mg L-1)}$$
(1)

Total suspended solids, mg
$$L^{-1} = \frac{(W_2 - W_1) \times 1000}{\text{Sample volume, mL}}$$
 (2)

where W_2 is weight of filter disc with dried residue and W_1 is weight of filter disc before use in milligram (mg).



Fig. 2 (a) Morphology of laterite soil at low magnification $5000 \times$ (b) morphology of laterite soil at high magnification $40000 \times$ (c) topography element contents of laterite soil by using energy dispersive X-ray analysis.



FT-IR measurement on the sludge was carried out at room temperature on a Nicolet iS10 Smart OMNI-transmission FT-IR Spectrometer. The sludge produced after coagulation with laterite soil was collected and dried in the oven at 105 °C for 2 hours. Solidified sludge was dried and ground into powder subsequently, dispersed in a matrix to mix with potassium bromide (KBr). The mixture was transferred to a die that has a barrel diameter of 13 mm, subsequently the die was pressed to form a disc. The disc was removed carefully from the die and placed in the FT-IR sample holder. The content in the disc was ready for the 4000–450 cm⁻¹ transmission spectrum analysis. For the mechanism elutriation, the intermediate compounds for methylene blue and methyl orange dyes removal were identified and analyzed with Gas Chromatography-Mass Spectrometry (GC-MS) (GC-2010 Plus, Shimadzu corporation, Japan) with BPX5 column.

3. Results and discussion

3.1 Effect of pH

Fig. 4 demonstrates the results of coagulation performance for methylene blue and methyl orange at different pH values. The results reveal that the dyes gave the highest performance at pH 2. Generally, when the solution shifted from acidic to alkaline condition, it led to decrease in color removal and increase in residual turbidity. When laterite soil is in contact with water, compounds in laterite soil: SiO₂ (36.30%), Al₂O₃ (27.10%) and Fe₂O₃ (26.86%) would form Si(OH)₄, Al(OH)₃ and Fe(OH)₃. SiO₂ is able to act as a degradation catalyst as stated in the research by Li et al.¹⁷ Lau et al.¹⁸ reported that pH 2 is the point of zero charge (PZC) for laterite soil. At PZC, silica was present in $[SiOH_2^+]$ and $[SiO_3^{2-}]$ forms, which were able to accept both cationic methylene blue and anionic methyl orange dyes. Simultaneously atmospheric oxides in laterite soil: Al₂O₃, Fe₂O₃, dissolved in strong acid to release Al³⁺ and Fe³⁺ ions which were then attracted to more stable anionic methyl orange dye molecules. Therefore, the optimal pH value for the maximal





degradation of both dyes were pH 2 at which the dye colloids and coagulant had agglomerated and settled down.

In alkaline condition, the performance of laterite soil to treat the dyes decreased. This happened because addition of NaOH to adjust the pH of the system caused the silica to form a stable compound, Na₂SiO₃ ¹⁹ as shown in the equation below:

$$Si(OH)_4 + 2NaOH \leftrightarrow Na_2SiO_3 + 3H_2O$$
 (3)

The removal of methylene blue could remain above 80% in alkaline condition because aluminum and ferric ions which react with OH⁻ ions tends to form hydroxylaluminate and hydroxyl-ferric anions.²⁰

$$Al(OH)_3 + OH^- \leftrightarrow Al(OH)_4^- \tag{4}$$

$$Fe(OH)_3 + OH^- \leftrightarrow Fe(OH)_4^-$$
 (5)

However, the residual turbidity of methylene blue increased at a fast rate. This was attributed to the absence of silica which functioned as flocculant in the system. For the anionic methyl orange, as the pH increased to alkaline condition, the color removal decreased gradually and the residual turbidity increased rapidly. This was happening because aluminum and ferric in laterite soil were present as hydroxylaluminate and hydroxyl-ferric anions. Thus strong repulsive forces occurred between these anions and anionic methyl orange. Consequently, no interparticle bridging and aggregation of particles took place. Cationic and anionic dyes at different pH range did affect the performance of laterite soil in coagulation process, thus optimum pH should be taken into consideration to ensure effective charge neutralization in the system. Effective charge neutralization by adsorption of oppositely charged ions would enhance colloidal flocculation.21

3.2 Zeta potential

Fig. 5 shows the changes of zeta potential for laterite soil as a function of pH for the cationic and anionic dyes. Zeta potential measurements indicate the surface charges present on the laterite soil particles when it exists in aqueous suspension.



Fig. 5 Zeta potential measurements for laterite soil as a function of pH.

Laterite soil would undergo acid-base amphoteric dissociation since it contains hydroxyls (OH⁻) on the surface (silanol group). A schematic diagram of the dissociation is shown in Fig. 6. The tendency for the hydroxyls to dissociate is strongly affected by pH. Addition of acid into dye solutions increased the concentration of protons in the solutions. Therefore SiO₃^{2–} was formed in the diffuse layer. As the solution became more acidic, particularly at pH lower than 2, zeta potential readings became higher. This indicates that the degree of repulsion between similar charges dispersed in the diffuse layer, hence the colloids resisted to aggregate.²² As a result, zeta potential at acidic pH indicated positive values. On the other hand, at alkaline pH, OH^{-} ions were adsorbed onto silica surfaces to form $SiOH^{+}_{2}$, resulting in negative zeta potential values. Hence, large diffuse electrical double layer took place.23 The PZC for the laterite soil with cationic and anionic dyes, both were detected at the pH value of 2.5 where silica colloids remained stationary in an electrical field. At this point, silica colloids aggregated and rearranged in order to balance the counter ions with dye particles. Meanwhile, zeta potential supported the effect of pH on the color removal and residual turbidity of methylene blue and methyl orange which have been discussed in Section 3.1.







Fig. 7 Scheme with intermediates and products proposed for the degradation of (a) methylene blue; (b) methyl orange.

3.3 Degradation mechanism of cationic methylene blue dye

Fig. 7a depicts degradation pathway of methylene blue at pH 2. Methylene blue is a cationic dye favorable to bind with negatively charged surface.²⁴ Therefore, the surface charge of silica which carries SiO_3^{2-} destabilized methylene blue through

charge neutralization by binding with the sulfate ion of methylene blue. When SiO_3^{2-} was ion tied up with the sulfate ion, methylene blue structure became unstable and led to breakage at the weaker strength bond. As decolorization took place in a rapid manner, thiazine was prone to cleave in the initial stage of





degradation which caused the disappearance of the absorbance peak at 664 nm under UV-Vis spectra (Fig. 8a). As verification, the FT-IR peaks shown in Fig. 9a from the range 1603 to 1394 cm⁻¹, which represents aromatic ring structures in methylene blue, had almost vanished after coagulation. This indicates destruction of polyaromatic structure in methylene blue. Hence, N,N-dimethylaniline (C₆H₅N(CH₃)₂) (intermediate I) degradation intermediate released from the methylene blue structure was identified in GC-MS analysis (Fig. 10).



Fig. 9 FT-IR analysis before ϑ after reaction for (a) methylene blue; (b) methyl orange.



Fig. 10 GC-MS analysis for N_1N -dimethylaniline (C₆H₅N(CH₃)₂).

Simultaneously, unstable anion molecule of RSiO₃⁻ (intermediate II) was formed. Subsequently, when two molecules of RSiO₃⁻ existed in the system, it tended to form siloxane molecule (R_2SiO_3). In general, one molecule of $SiO_3^{\ 2^-}$ was able to neutralize two molecules of cationic methylene blue by forming two molecules of N.N-dimethylaniline and one molecule of siloxane molecule (R_2SiO_3) (intermediate III). Instantly, the = NH of the siloxane molecule tended to destabilize and detach, subsequently forming diazene. Diazene (HN=NH), also known as diimide, is a strong reducing agent for carbon-carbon double bond, (-C=C-).²⁵ Diazene scissored the -C=C- of benzene rings. When the benzene rings were opened, linear products of hydrocarbon, (C_nH_n) were created. Aromatic amine of intermediate I had undergone diazene reduction to form simple hydrocarbon product. This has been confirmed from the FT-IR spectra whereby peaks within 875 to 791 cm⁻¹ entirely disappeared after coagulation. Lastly, the siloxane molecule with alkoxide group would undergo hydrolytic condensation reaction to form silsesquioxane as the final product of coagulation.²⁶ A broad peak in FT-IR graph from range 1169 to 1000 cm⁻¹ verifies the formation of silsesquioxane. The silsesquioxane characteristics of dimensionality, high symmetry, and nanometer size enhanced the formation of organosilicon compounds. The final product has built a strong sweeping flocculation in the system.

Degradation mechanism of anionic methyl orange dye 3.4

When laterite soil was present in anionic methyl orange dye system at pH 2, the surface charge of silica carries cationic

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charge has changed the molecular structure of methyl orange. The decrease of the absorption spectra intensities of methyl orange is shown in Fig. 8b. Degradation rate of methyl orange is significantly lower than methylene blue due to the molecular structures of both dyes.²⁷ As can be seen in this figure, the gradually disappearance of the characteristic band of methyl orange at 505.5 nm indicates that the first stage of degradation was the azo bond cleavage. The FT-IR band located at 1366 cm^{-1} which is assigned to azo bond of methyl orange has entirely vanished after reaction with laterite soil as shown in Fig. 9b. The breakage of azo bond led to formation of N,N-dimethyl-pphenylenediamine ((CH₃)₂NC₆H₄NH₂) (intermediate I) and p-amino-benzenesulfonic acid (C₆H₆NO₃S) (intermediate II) as illustrated in Fig. 7b. The -NH2 from intermediates I and II proned to combine into diazene. Subsequently, the intermediate I structure reduced to N_{N} -dimethylaniline (C₆H₅N(CH₃)₂) (intermediate III). Meanwhile, intermediate II had been attacked by silica instantly accompanied by aluminum and ferric ions. This happened since methyl orange is a strongly bonded dye which was hard to degrade. Higher attraction force is required to enhance the dye destabilization. Subsequently, intermediates IV and V were formed. When sufficient diazene was present to scissor the benzene rings of the intermediates IV and V, linear hydrocarbon products, C_nH_nO_n-Si=Al (intermediate VI) and $(C_nH_nO_n)_2$ -Si=Fe (intermediate VII) were formed. The FT-IR band within 1606 to 1519 cm⁻¹ range represents aromatic rings in methyl orange which had been scissored after addition of laterite soil. The positions at 3500 to 3200 cm^{-1} and 1650 to 1630 cm⁻¹ of FT-IR bands are evidence for the formation of intermediates VI and VII.28 From the proposed degradation pathway (Fig. 7b), Si≡Al was able to bind with only one molecule of methyl orange, whereas Si=Fe was able to bind with two molecules of methyl orange. Silica ion is more favorable to tie with oxide ions. Hence after aluminum and ferric had destabilized the methyl orange structure, these metal ions would be detached from silica and formed metal hydroxides, Fe–OH and Al–OH as detected in FT-IR 706 to 600 cm⁻¹ range. The free radical side of silica would attract oxide ions to form silsesquioxane. A broad peak in FT-IR graph from range 1160 to 1000 cm^{-1} is the verification of silsesquioxane formation. Similar to methylene blue, organosilicon structure was formed at the final degradation stage of methyl orange.

3.5 Sludge characteristics

Fig. 11 presents the sludge settling characteristics for methylene blue and methyl orange at the associated optimum dosages of laterite soil. The settling intervals were constructed until 200 min to observe the settling condition of sludge. During the initial 10 min of settling, the clarified water rose up whereas the sludge formed moved downwards by gravity force in a fast rate. For the proceeding settling, the settling rate began to decelerate as the sludge entered compression region. The volume of sludge continued to decrease until a time that it remained unchanged, specifically after 40 min of settling for both dyes. The treated dye solution zone and the settled sludge zone can be clearly differentiated. The maximum percentage of water recovery



Fig. 11 Settling characteristics (a) methylene blue (b) methyl orange.

obtained for methylene blue and methyl orange are 98 and 74%, respectively. Furthermore, the sludge settling velocity of methylene blue (0.27 mL s^{-1}) was faster compared to methyl orange (0.20 mL s^{-1}) . This confirm that methylene blue and methyl orange degradation led to the formation of high density organosilicon structure with good settling properties. Sludge volume index (SVI) for methylene blue and methyl orange are 18.69 and 26.77 mL g⁻¹, respectively, which are in the best range according to the standard SVI test. Methylene blue has lower SVI compared to methyl orange. This is because methyl orange requires higher dosage of laterite soil for complete color removal and degradation. Lower extent of sludge yielded is preferable since industries can manage the sludge easily, thus preserving the environment.

3.6 Sludge thermal degradability

Thermogravimetric analysis (TGA) profiles of sludge illustrated in Fig. 12 shows a weight loss of 1.43% in the temperature range of 100–200 °C. This phenomenon happened due to dehydration of sample and removal of volatile organic matter. An endothermic weight loss of 3.65% within the temperature range around 210–370 °C was observed. This endothermic weight loss was due to oxidation of organic substances containing C and H. As the energy of absorption was high, a partial oxidative decomposition of high concentration dye may be involved. When it reached the temperature of 398 °C, a sharp weight loss of 7.14% occurred. This weight loss contributed to further decomposition of the remaining dye molecules or dye interconnected with metal ions present in the sludge. The



Fig. 12 TGA and DTA of sludge.

decomposition of metal coordinated ions continued until the formation of metal oxide.²⁹ This behavior indicates that the sludge produced by laterite soil was thermally decomposable.

3.7 Comparison of the effectiveness of laterite soil as natural coagulant with chemical coagulant

A review on the effectiveness of aluminum-based coagulant, a chemical typed coagulant and a natural coagulant, laterite soil used are compared (Table 1). Patel and Vashi³⁰ and Qiu *et al.*³¹ revealed that without the presence of coagulant aid, high dosage of aluminum-based coagulant was required to ensure high performance of removal (70 000 mg L⁻¹ to treat 74.50% of textile wastewater; 36 000 mg L⁻¹ to treat 97.00% of printing wastewater). Only 23.00% removal was detected when 400 mg L⁻¹ of alum was used to treat dyeing wastewater. Without the

presence of color removal agent, alum could not effectively remove the colorant in the water; therefore color removal agent was essential to ensure high performance of alum in treating dye wastewater.³² With the presence of coagulant aids such as polyacrylamide based polymer (Cytec) and cethyltrimethyleammoniumbromide (CTAB), dosages of alum used had been successfully decreased. However the sludge yielded after coagulation was voluminous. Subsequently, higher expenses were required to deal with the voluminous toxic sludge yielded.³⁵ On the other hand, photocatalytic process has been proven to be effective for dye degradation.³⁶ Photocatalysis process is able to remove 80% of methylene blue at pH 9 using titanium dioxide (TiO₂) nanofilm³⁷ in 10 minutes. Besides, the photocatalysis process of methyl orange is reported at 81.3% at pH 6 using polyaniline modified zinc oxide (PANI/ZnO) in 2 hours.³⁸

Table 1 Comparison of effectiveness of laterite soil as natural coagulant with chemical coagulant									
Type of wastewater	Aluminum-based coagulant						Laterite Soil		
	Textile wastewater	Printing wastewater	Dyeing wastewater	Disperse and reactive dyes wastewater	Remazol red RB textile dye (25 ppm)	50 mg L^{-1}			
						Methylene blue	Methyl orange	Acid orange 7	
Flocculant	Without	Without	Without	Cytec	CTAB	Without	Without	Without	
рН	5.70-6.50	7.01	8.00	5.30	10.05	2.00	2.00	2.00	
Dosage, mg L^{-1}	70 000	36 000	400	200	100	2500	15 000	10 000	
Removal (%)	74.50	97.00	23.00	94.00	100.00	99.61	92.11	98.47	
SVI range	—	55.81	Large quantities	83.50	140.00 (voluminous)	18.69 (Best range)	26.77	21.70	
Effect	Aluminum-based coagulants tend to develop Alzheimer's disease in human being No possible hazards may present due to its naturalism.						v present		
References	30	31	33	34	19	This study	This study	18	

Contrast to chemical coagulant, laterite soil is able to treat cationic and anionic dye wastewater with a high performance at 99.61% and 92.11% without the presence of any coagulant aids and catalyst (photocatalysis). Moreover the sludge volume produced is very low and laid on the best range in the index of sludge volume. The massive impact of chemical coagulant to environment and human is the most significant. After coagulation process, the sludge formed by chemical coagulant are hard to degrade, thus tends to induce further environmental issues. Additionally, chemical coagulant especially aluminumbased coagulant had been proven for the development of Alzheimer's disease in human being. In the application of laterite soil as natural coagulant in coagulation, the sludge yielded is thermally decomposable and possessed zero hazards to environment and public.

4. Conclusion

A new concept for dye degradation by using laterite soil was demonstrated. Laterite soil was a newly found natural coagulant from natural resources which contained silica hybrid with aluminum-ferric as auxiliary agents. Successful cationic dye (methylene blue) and anionic dye (methyl orange) degradation was accomplished through charge neutralization, electrical double layer compression and sweeping flocculation mechanisms. Laterite soil was capable to degrade dye molecular structure into simple hydrocarbon structure with the formation of silsesquioxane as final product. The silsesquioxane products had promising flocculation effect and low sludge production through formation of high density and compact floc.

Abbreviations and symbols

Al_2O_3	Aluminum oxide
Al(OH) ₃	Aluminum hydroxide
$Al(OH)_4^-$	Hydroxylaluminate anion
Fe_2O_3	Ferric oxide
Fe(OH) ₃	Ferric hydroxide
$Fe(OH)_4^-$	Hydroxylferric anion
HCl	Hydrochloric acid
NaOH	Sodium hydroxide
PZC	Point of zero charge
SiO ₂	Silicon dioxide
SVI	Sludge volume index

Acknowledgements

The authors would like to express their thanks for the support by Universiti Sains Malaysia (USM) and Universiti Malaysia Perlis (UniMAP).

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