REMOVAL OF DYES BY SILICA NANOPARTICLES WITH IMMOBILIZED LACCASE

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REMOVAL OF DYSES BY SILICA NANOPARTICLES WITH IMMOBILIZED LACCASE

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To my beloved parent and family
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ABSTRACT

Dyes give a big impact on ecosystem; thus several methods have been developed for dye removal processes. This study investigated the dye removal by the combination of adsorption and biodegradation process. Silica nanoparticles (SN), modified silica nanoparticle (MSN), silica nanoparticle with laccase (SNL), and modified silica nanoparticle with laccase (MSNL) were synthesized. All samples were characterized with scanning electron microscope (SEM), nitrogen adsorption-desorption (NAD), Fourier transform infrared (FTIR), and energy dispersive X-ray (EDX). It was found that the introduction of cationic surfactant and laccase did not change the morphology but it affected the surface area, pore characteristics and chemical properties of the SN. The dye adsorption performance using SN and MSN was evaluated in batch adsorption experiment at various experimental conditions. The adsorption of methylene blue (MB) by SN showed a good adsorption performance ($q_e = 0.2291$ mmol/g) as compared to the MSN ($q_e = 0.0430$ mmol/g). In contrast, for methyl orange (MO), the MSN showed a very good adsorption performance ($q_e = 0.1849$ mmol/g), while no adsorption was observed for the SN. The pH values did not give any significant effect on the dye adsorption and the cetyltrimethylammonium bromide (CTAB) concentration of 1mM was found to be the maximum value for SN modification. The adsorption equilibrium and kinetic data for both MO and MB fit the Temkin and Langmuir isotherm models well, respectively while the kinetic adsorption data follows the Elovich kinetic model with film diffusion found to be the rate-limiting step. The dye adsorption process was found to be exothermic, spontaneous and physisorption. The regeneration shows that SN and MSN are reusable for multiple cycles. For the laccase immobilization, MSN performed higher laccase adsorption (1.6696 μmol/g) as compared to SN (1.1047 μmol/g). The removal of dye by SNL and MSNL was analyzed in term of adsorption and degradation of both MO and MB dyes. Results show that the removal of MB by SNL was higher ($q_e = 0.2573$ mmol/g) than SN ($q_e = 0.2291$ mmol/g). Meanwhile, removal of MO by MSNL was higher ($q_e = 0.2454$ mmol/g) as compared to MSN ($q_e = 0.1849$ mmol/g). These results demonstrated that the surface modification of SN by cationic surfactant gave higher catalytic activity of laccase, hence giving higher removal performance of dye. The adsorption isotherm data analysis shows that the SNL and MSNL are well fitted to the Langmuir and Temkin model respectively. The Elovich kinetic model is however the best model to describe the dye adsorption kinetic data of both SNL and MSNL. The dye removal by degradation was analyzed using Michaelis-Menten enzymatic reaction equation which found that higher specific activity was observed for MSNL (88.5724 U/g) as compared to SNL (22.6360 U/g). This resulted in higher initial enzymatic reaction velocity, $V_{max}$ (58.0 μM/min) for MO (MSNL) and lower for MB (SNL) (58.0 μM/min).
ABSTRAK

Pencelup memberi kesan buruk kepada ekosistem; jadi beberapa cara penyingkiran dikaji. Kajian ini mengkaji penyingkiran pencelup dengan gabungan proses penjerapan dan penguraian. Silika berzarah nano (SN), silika berzarah nano terubahsuai (MSN), silika berzarah nano dengan lakase (SNL), dan silika berzarah nano terubahsuai dengan lakase (MSNL) telah disintesis. Semua sampel dicirikan dengan mikroskop elektron imbasan (SEM), penganalisis penjerapan-penyahjerapan nitrogen (NAD), spektrometer Fourier transformasi infrared (FTIR) dan pembelau serakan tenaga sinar-X (EDX). Didapati kation surfaktan tidak mengubah morfologi tetapi menjejaskan luas permukaan, ciri liang dan sifat kimia SN. Penjerapan pencelup menggunakan SN dan MSN dinilai dalam eksperimen berkumpulan pada beberapa keadaan. Penjerapan pencelup biru (MB) menggunakan SN dan MSN menunjukkan penjerapan yang baik ($q_e = 0.2291 \text{ mmol/g}$) berbanding dengan MSN. Sebaliknya, untuk pencelup jingga (MO), MSN menunjukkan penjerapan yang sangat baik ($q_e = 0.1849 \text{ mmol/g}$), manakala tiada penjerapan pada SN. Nilai pH tidak memberi kesan yang ketara terhadap penjerapan dan kepekatan cetyltrimethylammonium bromide (CTAB) 1 mM didapati adalah nilai maksimum bagi pengubahsuaiyaan SN. Data penjerapan keseimbangan untuk kedua-dua pencelup MO dan MB berkation masing-masing mematuhi model sesuhu Temkin dan Langmuir, manakala data penjerapan kinetik mematuhi model kinetik Elovich dengan resapan filem sebagai kadar yang mengehadkan. Proses penjerapan adalah tindak balas luah haba, spontan dan jerapan fizikal. Penjanaan semula SN dan MSN adalah berjaya untuk beberapa kitaran. Untuk pengubahsuaiyaan lakase, MSN menunjukkan penjerapan lakase yang tinggi (1,6696 μmol/g) berbanding SN (1,1047 μmol/g). Penyingkiran pencelup oleh SNL dan MSNL telah dianalisis dari segi penjerapan dan penguraian untuk kedua-dua pencelup MO dan MB. Keputusan menunjukkan bahawa penyingkiran MB oleh SNL adalah tinggi ($q_e = 0.2573 \text{ mmol/g}$) daripada SN ($q_e = 0.2291 \text{ mmol/g}$). Manakala, penyingkiran MO oleh MSNL adalah tinggi ($q_e = 0.2454 \text{ mmol/g}$) berbanding MSN ($q_e = 0.1849 \text{ mmol/g}$). Ini menunjukkan pengubahsuaiyaan permukaan SN oleh bahan permukaan berkation meningkatkan aktiviti pemangkinan lakase dan seterusnya memberikan penyingkiran pencelup yang tinggi. Data penjerapan, garis sesuhu menunjukkan bahawa SNL dan MSNL masing-masing mematuhi dengan baik model sesuhu Langmuir dan Temkin. Model kinetik Elovich adalah model yang sesuai bagi penjerapan pencelup oleh SNL dan MSNL. Penyingkiran pencelup secara penguraian pula dinilai menggunakan persamaan tindakbalas enzim Michaelis-Menten yang mendapati bahawa aktiviti pemangkin adalah lebih tinggi pada MSNL (88.5724 U/g) jika dibandingkan dengan SNL (22.6360 U/g). Ini membawa kepada kelajuan tindak balas awal enzim, Vmax (58.0 μM / min) yang tinggi untuk MO (MSNL) dan rendah untuk MB (SNL) (58.0 μM/min).
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q_e - Adsorption capacity (mmol/g)
Q_{if} - Average concentration in the solid at infinite time
q_{max} - Maximum adsorption capacity (mg/mol)
Q_s - Average value of q (adsorption quantity) in a spherical
q_t - Adsorption capacity at time t (min) (mmol/g)
r - Radial position
R - Universal gas constant (8.314 J/mol.K)
R' - Adsorbent particle radius (m)
R^1 - Liquid film diffusion constant (min^{-1})
r^2 - Linear regression coefficient for isotherm and kinetic models
R_L - Favorability of dye adsorption on FSN and MSN
r_o - Radius of the adsorbent beads
R_p - Total particle radius
T - Absolute temperature (298 K)
U - Laccase activity (μmol/L.min)
V_{pore} - Pore volume (cm^3g^{-1})
α - Initial adsorption rate (mg/g.min)
β - Desorption constant (mg/g.min)
Γ - Surface coverage of surfactant (mmol/g)
ΔA - Increase in absorbance at 436 nm for laccase
ΔG^o - Gibb free energy change (kJ/mol)
ΔH^o - Enthalpy change (kJ/mol)
ΔS^o - Entropy change (kJ/mol.K)
χ^2 - Linear regression coefficient for isotherm and kinetic models
ε - Absorptivity of ABTS (29,300 M^{-1}.cm^{-1})
### LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>ABTS</td>
<td>Azino-bis(3-ethylbenzoline-6-sulfonic acid) diammonium salt</td>
</tr>
<tr>
<td>AC</td>
<td>Activated carbon</td>
</tr>
<tr>
<td>AOP</td>
<td>Advanced Oxidation Processes</td>
</tr>
<tr>
<td>APD</td>
<td>Ambient Pressure Drying</td>
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<tr>
<td>ATR</td>
<td>Attenuated Total Reflectance</td>
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<tr>
<td>BET</td>
<td>Brunauer-Emmet-Teller</td>
</tr>
<tr>
<td>BJH</td>
<td>Barrett-Joyner-Halenda</td>
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<td>BMCO</td>
<td>Blue multicopper oxidases</td>
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<tr>
<td>CI</td>
<td>Colour Index</td>
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<td>CMC</td>
<td>Critical micelle concentration</td>
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<tr>
<td>COD</td>
<td>Chemical oxygen demand</td>
</tr>
<tr>
<td>CTAB</td>
<td>Cetyltrimethylammonium bromide</td>
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<tr>
<td>EDX</td>
<td>Energy Dispersive X-Ray</td>
</tr>
<tr>
<td>EPR</td>
<td>Electron paramagnetic resonance</td>
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<tr>
<td>ETP</td>
<td>Effluent treatment plant</td>
</tr>
<tr>
<td>FTIR</td>
<td>Fourier Transform Infra-Red</td>
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<tr>
<td>HCl</td>
<td>Hydrochloric acid</td>
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<tr>
<td>HPLC</td>
<td>High performance liquid chromatography</td>
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<tr>
<td>LMS</td>
<td>Laccases Mediator Systems</td>
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<tr>
<td>MB</td>
<td>Methylene blue</td>
</tr>
<tr>
<td>MO</td>
<td>Methyl Orange</td>
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<tr>
<td>MSN</td>
<td>Modified silica nanoparticles</td>
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<tr>
<td>MSNL</td>
<td>Laccase modified silica nanoparticles</td>
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<tr>
<td>NAD</td>
<td>Nitrogen Adsorption/Desorption</td>
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<td>PFO</td>
<td>Pseudo-first-order</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>PSO</td>
<td>Pseudo-second-order</td>
</tr>
<tr>
<td>SDS</td>
<td>Sodium dodecyl sulphate</td>
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<tr>
<td>SEM</td>
<td>Scanning Electron Microscopy</td>
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<tr>
<td>Si-O</td>
<td>Silica aerogel</td>
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<tr>
<td>Si-OH</td>
<td>Silanol group</td>
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<td>SN</td>
<td>Silica nanoparticles</td>
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<td>SNL</td>
<td>Laccase silica nanoparticles</td>
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<td>T1</td>
<td>Type-1 copper of blue multicopper oxidases</td>
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<td>T2</td>
<td>Type-2 copper of blue multicopper oxidases</td>
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<tr>
<td>T3</td>
<td>Type-3 copper of blue multicopper oxidases</td>
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<tr>
<td>TEA</td>
<td>Triethylamine</td>
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<td>TEOS</td>
<td>Triethoxysilane</td>
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Data of dyes adsorption at various agitation times. Experimental conditions: \([\text{Dye}]_i = 0.06 \text{ mM}; \text{[CTAB]} = 5 \text{ mM}; \text{initial pH} = 7; \text{agitation time} = 1 \text{ hour}; \text{adsorbent dosage} = 1\text{mg/ml}; \text{temperature} = 30 \pm 0.5 \, ^\circ\text{C}; \text{and agitation speed} = 250 \, \text{rpm}.\)

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[CTAB] = 5 Mm; initial pH = 7; agitation time = 1 hour; absorbent dosage = 1mg/ml; temperature = 30 ± 0.5 °C; and agitation speed = 250 rpm.

E

Data collections for laccase immobilization onto SN

E.1

Data for amount of laccase adsorb onto SN and MSN at various agitation times. Experimental conditions: agitation time = 1 hour; initial pH = 5; temperature = 30 ± 0.5 °C; [laccase]₀ = 0.05 mM; [CTAB]₀ = 0.5 mM; dosage = 50 mg/ml and agitation speed = 200 rpm.

E.2

Data for laccase immobilization onto (a) SN and (b) MSN at different pH. Experimental conditions: agitation time = 1 hour; temperature = 30 ± 0.5 °C; [laccase]₀ = 0.05 mM; [CTAB]₀ = 0.5 mM; dosage = 50 mg/mL; and agitation speed = 200 rpm.

E.3

Data for laccase immobilization at various initial CTAB concentrations. Experimental conditions: agitation time = 1 hour; temperature = 30 ± 0.5 °C; [laccase]₀ = 0.05 mM; support dosage = 50 mg/mL; [pH]₀ = 5; and agitation speed = 200 rpm.

E.4

Data for laccase immobilization onto (a) SN and (b) MSN at various initial laccase concentrations. Experimental conditions: agitation time = 1 hour; temperature = 30 ± 0.5 °C; [CTAB]₀ = 5 mM; support dosage = 50 mg/mL; [pH]₀ = 5; and agitation speed = 200 rpm.

E.5

Data for thermal stability of free laccase and immobilized laccase.

F

Data collection for dyes removal by SN and laccase silica nanoparticles

F.1

Data of dyes adsorption at various initial dyes concentrations. Experimental conditions: initial pH = 7; agitation time = 2 hours; adsorbent dosage = 1mg/mL; [CTAB]₀ = 5 mM; [laccase]₀ = 0.1 mM; temperature = 30 ± 0.5 °C; and agitation speed = 250 rpm.

F.2

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F.3

Data of dyes adsorption at various agitation times.
Experimental conditions: [Dye]_i = 0.3 mM; [CTAB]_i = 5 mM; [laccase]_i = 0.1 Mm; pH_i = 7; agitation time = 1 hour; adsorbent dosage = 1mg/mL; temperature = 30 ± 0.5 °C; and agitation speed = 250 rpm.

Data for pseudo-first-order, pseudo-second order and elovich of adsorption kinetic models.

Experimental conditions: [Dye]_i = 0.3 mM; [CTAB]_i = 5 mM; [laccase]_i = 0.1 Mm; pH_i = 7; agitation time = 1 hour; adsorbent dosage = 1mg/mL; temperature = 30 ± 0.5 °C; and agitation speed = 250 rpm.

Data for determination of film diffusion coefficient (D_f) and effective diffusion coefficient (D_eff) of dye adsorption. Experimental conditions: [Dye]_i = 0.3 mM; [CTAB]_i = 5 mM; [laccase]_i = 0.1 Mm; pH_i = 7; agitation time = 1 hour; adsorbent dosage = 1mg/mL; temperature = 30 ± 0.5 °C; and agitation speed = 250 rpm.

Data for removal of dyes by SN and laccase silica nanoparticles using initial dye concentrations of (a) 0.05 mM, (b) 0.1 mM, (c) 0.2 mM, (d) 0.3 mM, and (e) 0.5 mM. Experimental condition: agitation time = 2 hours; dosage = 1mg/mL; temperature = 30 ± 0.5 °C; and agitation speed = 250 rpm.
CHAPTER 1

INTRODUCTION

1.1 Research Background

Over the last century, dyes play an important part in the economy of many countries in which they have been used in many industries such as textile, foods, plastics, leather and pulp industries. Apart of economic benefits, these industries also contribute to water pollution because during processing, 2 - 50% of dyes that are not fixed onto the textile will be discharged as wastewaters (Robinson et al., 2001; Wesenberg et al., 2003; Murugesan et al., 2007; Pandey et al., 2007; Khlifi et al., 2010). Dyes can give a big impact on ecosystem as they increase the turbidity of water and disturb the photosynthesis process in aquatic flora as well as to cause vomiting, increased heart rate, diarrhea, shock, cyanosis, jaundice, and tissue necrosis on human beings (Chen et al., 2011).

Generally, dyes can be categorized into many classes, for instance, based on charge characteristics they can be classified into cationic, anionic and non-ionic dyes. The cationic dye is a basic dye consisting of chromophores from amino groups such as cyanine, hemicyanine and azine that producing color in dyes (Robinson et al., 2001). An example of the cationic dyes is methylene blue (MB) which finds wide applications in coloring paper, temporary hair colorant, dyeing for
cottons, wools, coating for paper stock and silk (Rafatullah et al., 2010). The anionic dye however consists of chromophores which are mostly from azo and anthraquinone groups. It can be further classified into acid, direct and reactive dyes. Methyl orange (MO) is an example of the acidic anionic dyes which is commonly used in dyeing of textile, printing, paper, wood, pharmaceutical industries, silk, wool, polyamide, modified acrylic and polypropylene fibers (Amran et al., 2011). The non-ionic dye refers to disperse dye, also consists of chromophores which are mostly from azo and anthraquinone groups. The non-ionic dye is not ionized in aqueous medium and more resistant to degradation due to their fused aromatic ring structure (Robinson et al., 2001; Fu and Viraraghavan, 2001). They are usually used in dyeing a polyester fiber.

The applications of dyes in many dyeing processes have generating dye wastewaters which require treatment to remove or recover dyes before charging to the surrounding environment. Several methods have been used in removal of dyes include physical (Amran et al., 2011; Errais et al., 2011; Gil et al., 2011), chemical (Fang et al., 2010) and biological (Robinson et al., 2001; Fu and Viraraghavan, 2001) methods. These methods offer several advantages and drawbacks over others. The combination of adsorption and biodegradation processes has found to be the best method for water re-use in term of flexibility, initial cost and simplicity of the operation, and environmental friendly (Robinson et al., 2001; Amran et al., 2011).

One of the attractive solution in biodegradation of dyes is based on laccase technologies since it have a high potential in degrading of dyes of diverse chemical structure especially for synthetic dyes (Abadulla et al., 2000). Laccase is an extracellular enzyme having molecular weight of approximately 60-70 kDa and the acidic isoelectric point is of around pH 4. It is a monomeric protein, glycoprotein covalently linked to carbohydrate moieties (10 - 45 %) that contributes to its high stability (Durán and Esposito, 2000). Laccase has variety of applications in biotechnology because of its high activity, selectivity and specificity (Mateo et al., 2007). The industrial use of the laccase is however still limited due to their relative instable under operational conditions such as high temperature. The exposure to other denaturants and organic solvents through the direct contact of laccase with
organic solvents affect the catalytically active conformation of the laccase (Markvicheva et al., 2005).

Therefore, laccase immobilization technology was established to reduce these limitations by increasing the thermostability of the laccase and also it’s resistant to the extreme conditions and chemical reagents. Recently, various immobilization methods of laccase have been reported such as covalent bonding, cross-linking, adsorption and entrapment. Among these methods, adsorption is the simplest since it does not require any pre-activation step of the supports which means that the laccase is attached to the matrices of the supports through the non-covalent interactions either by the hydrogen bonding, van der Walls forces, or hydrophobic interactions via the salt linkage (Costa et al., 2005; Brena and Viera, 2006). Consequently, many supports have been proposed for immobilization of laccase (Durán and Esposito, 2000). These include organic supports such as natural polymers or synthetic polymers and inorganic supports such as silica materials (Brena and Viera, 2006).

In recent years, many researches focused on silica based porous materials as absorbents such as silica gel (Vihar, 1996), silica aerogel (Liu et al., 2010), nanoporous silica (Anbia and Hariri, 2010; Anbia and Salehi, 2012) and mesoporous silicas (Fu et al., 2011; Yokoi et al., 2012) for dye removal processes because of their large surface area and high dye removal efficiency (Vihar, 1996; Anbia and Hariri, 2010; Fu et al., 2011; Yokoi et al., 2012). Nevertheless, the use of silica nanoparticles as an adsorbent for dye removal process has hardly reported by any researchers. However, they were used in the separation processes for the removal of BTEX (Kim et al., 2013; Kim et al., 2014), removal of oil (Cho et al., 2014) and extraction of phenolic compound (Zhao et al., 2008).

Silica nanoparticles can be synthesized using sol-gel process which is economical, versatile and simple technique. Many synthesis approaches have been reported and it has been found that the templating technique is the most common method used for producing silica nanoparticles with mesoporous structures (Kim et
al., 2013; Kim et al., 2014). By using surfactant, colloidal crystal, emulsion, latex spheres and even bacteria as the structural templates, the pore size distribution of the porous solid obtained can be controlled (Li et al., 2004). The typical examples of this group of silica nanoparticles are SBA-15, MCM-41 and HMM (Fuertes, 2004; Slowing et al., 2006; Guan et al., 2000). Another approach of course without the use of templating technique producing silica nanoparticles of silica gel types of materials. These include silica cryogel and silica aerogel which depend on the drying procedures adopted in synthesis process. The hydrolysis of silica precursors such as tetraethyl orthosilicate (TEOS) catalyzed by acid or base catalyst followed by the drying process is the most common sol-gel route in silica nanoparticles synthesis.

The silica nanoparticles have basically negative charge surface as a result of partial substitution of Si$^{4+}$ and the excess negative charge can be compensated by exchangeable cations such as Na$^+$, K$^+$, Ca$^{2+}$ or Mg$^{2+}$. This negative charge surface is due to the presence of Si-O and Si-OH groups make them good absorbents for cationic dyes (Anbia and Hariri, 2010). However, they are unsuitable for adsorption of anionic dyes because of repulsion of the same ionic charge between the silica surfaces and dyes. The surface modification is therefore necessary so that they can be used for various types of dye. It was reported that the surfactant was used in surface modification of zeolites (Alver and Metin, 2012; Jin et al., 2008), bentonite (Ozcan et al., 2007) and sepiolite (Ozcan and Ozcan, 2005) for removal of dyes.

1.2 Problem Statement

Adsorption is one of the common methods used for treatment of dyes wastewater because it is a simple and economical process. However, this process only involves the transfer of waste dyes from liquid to solid state. The complete elimination of the dyes cannot be achieved solely by adsorption process. One of the attractive solutions to treat the dye wastewaters is by the combination of adsorption
and biodegradation. It was reported that the immobilized laccase has been used for the biodegradation of dyes (Zille et al., 2003). The applications of the free and modified silica nanoparticles as adsorbents as well as the enzymatic support have so far not been reported. In this study, the silica nanoparticles were synthesized, modified and used as adsorbents and enzymatic support for removal of dyes from an aqueous solution. The silica nanoparticles will act as absorbent and catalytic support for laccase. It is expected that the dye will be removed by adsorption onto the silica nanoparticles and then will also undergo the biodegradation by the immobilized laccase. The advantages of the silica nanoparticles, among others are non-toxic and biocompatible (Li et al., 2004; Cho et al., 2014).

1.3 Objectives and Scope of Research

The objectives of this study are:

a) To synthesize, modify and characterize the silica nanoparticles

Silica nanoparticles (SN) were prepared by hydrolysis and condensation reactions of tetraethyl orthosilicate (TEOS) followed by drying process at ambient temperature and pressure. The synthesized silica nanoparticles were then modified using cationic surfactant (cetyltrimethylammonium bromide, CTAB). The concentration surfactant was determined using two-phase titration technique. The silica nanoparticles (SN) and surfactant modified silica nanoparticles (MSN) were characterized using nitrogen adsorption/desorption analysis (BET), scanning electron microscope (SEM), and Fourier transform infrared spectroscopy (FTIR) and elemental composition using Energy Dispersive X-Ray (EDX).

b) To study the dye removal process by adsorption onto silica nanoparticles

The adsorption process of dyes by the silica nanoparticles (SN) and surfactant modified silica nanoparticles (MSN) was studied using methylene blue (MB) and methyl orange (MO) as cationic and anionic dyes, respectively. Adsorption
parameters such as pH, temperature, dye concentration, and contact time were studied. The adsorption data were analyzed using the existing isotherm and kinetic models. The reusability of the SN and MSN was also studied.

c) To study the dye removal process by laccase silica nanoparticles

In this study, the silica nanoparticle (SN) and surfactant modified silica nanoparticle (MSN) were used as supports for the laccase immobilization. The immobilization process was investigated at various pH, initial CTAB concentrations, and initial laccase concentrations. The catalytic activity of laccase was determined by using 2,2’-azino-bis(3-ethylbenzoline-6-sulfonic acid) diammonium salt (ABTS) as a substrate. The thermal stability of SNL and MSNL were also investigated. The performance of the laccase silica nanoparticles (SNL) and laccase modified silica nanoparticles (MSNL) was evaluated using methylene blue (MB) and methyl orange (MO). The amount of the MB and MO degraded by the SNL and MSNL respectively was determined by subtracting the dye removal by SNL and MSNL with respectively by SN and MSN. The dye removal data were analyzed using Michaelis-Menten kinetic model, adsorption isotherm models and kinetic adsorption models.

1.4 Thesis outline

This thesis consists of five chapters. Chapter 1 presents an introduction to the research which comprises of the research background, problem statement, and research objectives and scopes. The detailed discussions about dyes, dye wastewaters and dye removal technologies are presented in Chapter 2. Chapter 3 presents all the methods used in the present study followed by Chapter 4 in which all results are presented and discussed. Chapter 5 summarizes the research findings with some recommendations for future research.
1.5 Summary

The recovery of dyes from dye wastewaters is not economically attractive for dilute dye wastewaters. Adsorption couple with degradation is an attractive technique for removal and thus eliminating dye from such system. Adsorption provides a mean to concentrate the dilute dye and thus degradation it simultaneously which can be achieved at mild conditions using immobilized enzymes such as laccase immobilized on the adsorbent as a support. This will be the subject of the present study towards developing an alternative technology for the dyeing industries for treating their waste before discharging into surrounding environment safely.
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