Removal of Reactive Dye by Adsorption over Chemical Pretreatment Coal Based Bottom Ash

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Abstract

The coal based bottom ash from Thailand Power Plant has been used as the adsorbent for the removal of reactive dye in aqueous solution. The bottom ash was pretreated with 1 N HCl, 1 N HNO₃, and 30% H₂O₂ before the adsorption tests. Adsorption of the pretreated bottom ash has been studied as a function of particle size, contact time, initial solution pH, and initial solution concentration. The ability to adsorb reactive dye (in terms of percentage dye removal) of these chemical treated bottom ashes are not significantly different. The adsorption reached an equilibrium state at about 15 hours from the beginning of the experiments. The adsorption capacity at the equilibrium state increased as the size of the particles decreased. This was due to the increase in surface area of the adsorbents. The maximum adsorption occurred at the initial solution pH lower than 2 for all adsorbents with the highest percentage of dye removal and the highest amount dye adsorbed of 75.8 and 0.1 mg/g adsorbents, respectively, for the H₂O₂ treated bottom ash. With varying the initial solution concentrations, the results showed that the adsorption capacity decreased as the initial solution concentration increased which was limited by the amount of the adsorbents in the system. Adsorption equilibrium data were fitted with both Langmuir and Freundlich adsorption isotherms with the correlation coefficient of 0.947 and 0.937, respectively.

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1. Introduction

In Thailand, there are about 2075 million tons of coal reserves. Approximately 99% of these coals are lignite and sub-bituminous. In 2011, the total coal consumption in Thailand was about 36 million tons, whereas 19 million tons were domestic coal and 17 million tons were imported from Indonesia, Australia, China, etc. The imported coal usually is bituminous class [1]. In the near future, except for natural gas, coal seems to be the main fuel for electricity generation and industry because of its competitive price. The estimated coal ash generated from coal combustion would be around 4 million tons per year (based on the average ash content of coal which is approximately 10% by weight). About 3 million tons of fly ash and 1 million tons of bottom ash are produced annually. In Thailand, coal ash is classified as a hazardous waste which might cause significant environmental problems. The hazardous constituents in coal ash can migrate and contaminate to both ground water and surface water, and hence living organism if these ashes are disposed improperly. At present, both bottom ash and fly ash from coal fired power plants in Thailand are sold to cement and concrete production industries, which seems to be surplus right now. An attempt to find an alternative way of coal based bottom ash utilization to reduce the burden of waste disposal is essential.

On burning coal, bottom ash or heavy ash will settle at the bottom of furnace, while fly ash will be carried over with flue gas and will be trapped by bag filter or other particle collectors. Bottom ash particles are physically coarse porous, granular and grayish in color. The particle size ranges from fine gravel to fine sand. The specific gravity of bottom ash varies from 1.39 to 2.33 depending upon its chemical composition. In general, bottom ash forms up to 25% of total ash, while fly ash forms the remaining 75%. Bottom ash is mainly composed of silica, alumina, and iron with small amount of calcium, magnesium, and sulfate etc. Its chemical composition is controlled by the source of the coal and combustion conditions. Both fly ash and bottom ash from coal fired power plant are known to contain several toxic substances, such as Pb, Zn, Cd, and Cu, etc. Generally, more heavy metals are released from fly ash than bottom ash [2, 3]. Therefore, bottom ash has been used as one of the ingredients of concrete and admixtures used in the construction of roads and bridges [4].

Recently, there have been some investigations on the adsorption of dye using bottom ash as alternative adsorbents. Dincer et al. [5] used raw coal bottom ash from thermal power plant in Turkey to adsorb reactive dyes. The amount of dye adsorbed onto bottom ash was measured as a function of contact time, initial dye concentration and pH by batch experiments. The most suitable pH for reactive dye adsorption onto the raw bottom ash was 7. The adsorption isotherm from his studies is best described by Freundlich isotherm. Gupta’s group [6] [7] [8] also reported adsorption study of several dyes using coal bottom ash as an adsorbent. In their experiments, bottom ash was pretreated with 30% w/v hydrogen peroxide to oxidize adhering organic materials before adsorption tests. The adsorption of dye depends on pH, size of adsorbents, dye concentration, temperature, etc. The results showed that bottom ash can be used effectively as an adsorbent for dye removal from wastewater.

In addition, Genc and Oguz [9] investigated adsorption of two acid dyes onto bottom ash by performing batch equilibrium experiments with pH, ionic conductivity, initial dye concentration and temperature as variables. The color removal efficiency of bottom ash could reach 50% depending on the initial dye concentration. The adsorption equilibrium data of acid dyes onto the surface of bottom ash at different operating conditions were best described by the Langmuir model. Wu and his colleagues [10] prepared activated carbon from unburnt coal in bottom ash by soaking in potassium hydroxide (KOH) solution and activated for 1 h at 780 °C. The adsorption capacities of methylene blue, acid blue 74, and 4-chlorophenol for the activated carbon from unburnt coal were 2.40–2.88, 0.57–1.29, and 2.34–5.62 mmol/g, respectively. The equilibrium adsorption data of methylene blue, acid blue 74, and 4-chlorophenol from aqueous solutions on these activated carbons at 30 °C were best fitted by the Langmuir model with the correlation coefficient, $r^2 > 0.9968$.

Reactive dyes are widely used in Thailand’s textile industry, and large fractions of reactive dyes (10-50%) are wasted during dyeing process. Due to their strong interaction with many surfaces of synthetic and natural fabrics, reactive dyes are used for dyeing wool, cotton, nylon, silk, and modified acrylics [11]. Discharging dyes into water
streams can cause environmental damage as the dyes give water undesirable color and reduce sunlight penetration, with some being toxic or carcinogenic. The conventional aerobic biodegradation was found to be inefficient for complete elimination of many reactive dyes. Chemical coagulation and flocculation are also ineffective since reactive dyes are highly soluble in water. Generally, adsorption, ion exchange, and membrane filtration are effective for removing reactive dyes without producing unwanted by-products [12]. In this study the coal bottom ash from Thailand thermal power plant was pretreated with various chemicals, including hydrochloric acid, nitric acid and hydrogen peroxide, which are the chemicals generally used in treating the activated carbon. Then these adsorbents were tested for adsorption capacity as a function of pH, particle sizes, contact time, dye concentration. The adsorbates used in the experiment were commercial Reactive Blue 49 and Ramazol Brilliant Blue (Reactive blue 19), which are anthraquinone dyes. The obtained equilibrium isotherms were fitted well with both Langmuir and Freundlich models.

2. Materials and Methods

2.1. Materials

Coal bottom ash was obtained from the Thermal Power Plant in Thailand, located in the eastern seaboard industrial estate. This thermal power plant uses imported bituminous coals from Australia and Indonesia as the main fuel. The bottom ash is grayish in color with irregular shape. The bottom ash was pretreated with 1 N nitric acid (HNO₃), 1 N hydrochloric acid (HCl), and 30% w/v hydrogen peroxide (H₂O₂) before the adsorption tests. The specific surface area of the raw bottom is 6.78 m²/g. The specific surface area was determined by the BET-N₂ method using a Quantachrome Autosorb-1 surface area analyzer.

Two commercial reactive dyes were used as adsorbates in the experiments. Reactive Blue 49 was obtained from a local textile industry, and Ramazol Brilliant Blue R (Reactive Blue 19) was obtained from Sigma Aldrich Company. Reactive Blue 49 has molecular weight of 882.186 g/mol, and its molecular formula is C₃₂H₂₃CIN₇Na₃O₁₁S₃. Ramazol Brilliant Blue R has molecular weight of 626.54 g/mol, and its molecular formula is: C₂₂H₁₆N₂Na₂O₁₁S₃. Both dyes are anthraquinone dyes. The chemical structures of these dyes are shown in Fig.1. The synthetic wastewaters were prepared by dissolving dyes in deionized water to produce a stock solution of 1,000 mg/l (pH 7). This stock solution was diluted in desired proportions to produce solutions with different initial dye concentrations. All chemicals used in the experiments are AR grade.

![Chemical structure of Reactive Blue 49 and Ramazol Brilliant Blue R](image)

Fig. 1 Chemical structure of (a) Reactive Blue 49 [13] (b) Ramazol Brilliant Blue R [14]

2.2. Adsorbents Preparation

The bottom ash was first washed with deionized water before being dried overnight. The dried bottom ash was then ground and treated with 1 N nitric acid (1 N HNO₃), 1 N hydrochloric acid (HCl), and 30% w/v hydrogen peroxide for 24 h to remove adhering organic impurities. The chemical treated bottom ash was washed with deionized water until the neutral pH was reached, then dried in an oven at 105 °C for 2 hours. The prepared bottom ash was further activated in a furnace at 500 °C for 1 hour, and then sieved into three sizes; less than 0.5 mm, 0.5-1.0 mm, and 1.0 – 2.0 mm. Finally all the prepared adsorbents were stored in vacuum desiccators until required.
2.3. Adsorption Studies

Adsorption studies of prepared bottom ash were performed at 25 °C. For every adsorption study, a series of 150 mL volumetric flasks containing 50-100 ml volume of dye solutions at different concentrations were employed at desired pH. The dye solution pH was adjusted with 0.1 N sodium hydroxide (NaOH) or 0.1N hydrochloric acid (HCl) to desired initial pH prior to do the experiment. A specific amount of adsorbent of a particular particle size was added into each flask and was periodically agitated at 200 rpm, until the equilibrium was reached (approximately 15-24 hours). The solution was then filtered thru a 0.45 µm syringe filter, and the uptake of the dye was monitored spectrophotometrically by measuring absorbance at $\lambda_{\text{max}}$ of 590 nm for Ramazol Brilliant Blue R, and of 586 nm for the Reactive Blue 49.

3. Results and Discussions

3.1. Characteristics of Adsorbents

The specific surface areas, pore volumes, and pore diameters of all adsorbents are given in Table 1.

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>Surface Area (m²/g)</th>
<th>Pore Volume (cm³/g)</th>
<th>Pore Diameter (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw bottom ash</td>
<td>6.68</td>
<td>11.9 x 10⁻³</td>
<td>71.4</td>
</tr>
<tr>
<td>1 N HCl pretreated bottom ash</td>
<td>6.72</td>
<td>8.09 x 10⁻³</td>
<td>48.2</td>
</tr>
<tr>
<td>1 N HNO₃ pretreated bottom ash</td>
<td>7.93</td>
<td>8.28 x 10⁻³</td>
<td>41.8</td>
</tr>
<tr>
<td>H₂O₂ pretreated bottom ash</td>
<td>4.48</td>
<td>3.35 x 10⁻³</td>
<td>29.9</td>
</tr>
</tbody>
</table>

Typical values of BET surface area for commercial adsorbents are usually in the order of 100 - 1000 m²/g. The BET surface areas of the prepared bottom ashes as shown on Table 1 were very low compared to those of conventional adsorbents. The average pore diameters were 3-7 nm, which were mesopores based on the classification of the International Union of Pure and Applied Chemistry (IUPAC) [15]. After pretreated with concentrated acid and hydrogen peroxide, the porosity of these bottom ashes were not significantly changed. These chemical pretreatments may alter only chemical properties of the functional groups on the surfaces.

3.2. Effects of Initial pH and Particle Size

The adsorption study of Reactive Blue 49 on bottom ashes (pretreated with 30% H₂O₂, 1 N HNO₃, and 1 N HCl) was carried out at 25 °C and varying pH range (pH 1.5–10) with initial dye concentration of 10 mg/L. The amount of adsorbent used in this study was 10 g in 100 ml of dye solution. Three different particle sizes of adsorbent; < 0.5 mm, 0.5-1.0 mm, and 1.0-2.0 mm were examined in this experiment. The results showed a decline in the amount of dye adsorbed at higher pH for all particle sizes and all adsorbents. Plots of pH versus uptake of dye at 25 °C with different particle sizes and adsorbents are shown in Fig 2, which illustrates a constant decrease in the uptake of dye above pH 4.0. And, thereafter no change in the amount of dye uptake was observed. Maximum uptake of the dye (0.12 mg/g adsorbent), which corresponds to 96% dye adsorption, was achieved at pH < 2.0 for H₂O₂ pretreated bottom ash, with particle size less than 0.5 mm. The uptake of the dye increased as the particle sizes decreased clearly indicates the increase of surface area per volume, making it more accessible for dye adsorption. Figure 2b shows maximum adsorption of the dye over all the adsorbents at low pH. Except for the bottom ash that was pretreated with 1 N HNO₃, it gives the maximum dye adsorption at pH of 2.0. The results are in good agreement with the results of Mittal [8] and Órfão [16]. Where, they clearly explained that the adsorption process of the reactive dye on the adsorbents involves the electrostatic forces which are the interactions between the negative charges present in the dye molecules and the positively charged center of the adsorbent surface. At low pH (pH < pH_{pzc}), the bottom ash surface becomes positively charged favoring the adsorption of anionic species on the dye.
molecules. On the other hand, at high pH (pH > pH_{pc}), the bottom ash surface becomes negatively charged which is not favoring the adsorption of anionic species on dye molecules.

The adsorption of the Ramazol Brilliant Blue R on the chemical pretreated bottom ashes also showed similar pH effects. The adsorption of dye rapidly decreased as the pH increased and no obvious change in dye uptake was observed as pH increased higher than 4.0. The maximum dye uptake occurred at pH 3.0 for bottom ash pretreated with 1 N HNO₃ and 1 N HCl, and at pH 2.0 for bottom ash pretreated with H₂O₂. However, 1 N HCl pretreated bottom ash showed superior dye adsorption capacity over the other adsorbents for the adsorption of Ramazol Brilliant Blue R. For all subsequent experiments, the adsorption of Reactive Blue 49 was carried out on the H₂O₂ bottom ash at pH 2.0, the Ramazol Brilliant Blue adsorption was carried out on HCl-pretreated bottom ash at pH 3.0, which were the optimum pH for each dye.

3.3. Effect of Contact Time

Adsorption experiments were carried out to find the equilibrium contact time with a fixed adsorbent dose of 50 g in 500 ml dye solution at pH of 2.0 for reactive Blue 49, pH 3.0 for Ramazol Brilliant Blue R, and at 30 °C temperatures. The solution was continually agitated with mechanical stirrer. The samples of dye solution were taken with interval of 1 h until the equilibrium was reached. The uptakes of Reactive Blue 49 on H₂O₂ pretreated bottom ash and of Ramazol Brilliant blue R on HCl-pretreated bottom ash as a function of time are shown in Figure 3. The uptake of Reactive blue 49 on H₂O₂ pretreated bottom ash increased rapidly in the first 2 hours, and gradually increased after that (Figure 3a). More than 70% of the adsorption achieved in about 4 hours. The equilibrium adsorption was reached in 15 hours. The uptake of Reactive blue 49 on H₂O₂ pretreated bottom ash increased rapidly in the first hour, then gradually increased after 1 hour (Figure 3b). Figure 3b also shows the effect of the adsorbent dose on contact time. At high adsorbent dose, the equilibrium reached faster than that of low dose, i.e., 10 hours for 15 g adsorbent, and 20 hours for 5 and 10 g adsorbent. These results confirmed that the equilibrium was established for all previous experiments. Although Ramazol Brilliant Blue R has lower molecular weight and smaller size than Reactive Blue 49, the equilibrium contact times of both dyes were not significantly different.

3.4. Effect of Adsorbent Dose

The effect of adsorbent dose on the removal of Reactive Blue 49 was investigated at 20 mg/l dye concentration. A range of 10-50 g of adsorbents was mixed with 500 ml of the dye solution and the effect of adsorbent dose was studied at pH of 2.0, 25 °C with particle size < 0.5 mm. The results displayed in Fig. 4 shows that as adsorbent
quantity increased, dye adsorption decreased. Actually, the increase in adsorbent dosage mainly increased in sorptive surface area and availability of more adsorption sites. The decrease in dye uptake was mainly due to the limited amount of dye molecules in solution, and the dye concentration may be very dilute for this range of the adsorbent dosage. As shown in Fig. 3b, the increase in adsorbent dose from 5 g to 10 g in 50 ml solution with an initial dye concentration of 100 mg/l increased the equilibrium dye uptake from 0.5 to 0.8 mg/g adsorbent. On the other hand, the increase dosage from 10 g to 15 g did not show any significant change in dye uptake for the adsorption of Ramazol Brilliant Blue R, since the maximum equilibrium dye uptake was reached.

![Fig. 3](image)

**Fig. 3** Effect of contact time (a) for adsorption of Reactive Blue 49 on H2O2 pretreated bottom ash at 25 °C, at dye concentration of 10 mg/l, adsorbent dose = 50 g in 500 ml solution, particle size < 0.5 mm., pH 2.0. (b) for adsorption of Ramazol Brilliant Blue R on HCl pretreated bottom ash at 25 °C, at dye concentration of 100 mg/l, adsorbent dose = 5, 10, and 15 g in 50 ml solution, particle size = 0.5-1.0 mm., pH 3.0.

![Fig. 4](image)

**Fig. 4.** Effect of amount of adsorbent for the removal of Reactive Blue 49 (initial concentration = 20 mg/l) using H2O2 Pretreated bottom ash (sieve size = < 0.5 mm at 250 °C and pH 2.0, with 15 hour contact time.

3.5. Effect of Initial Dye Concentration

The uptake of the dye, Reactive Blue 49 and Ramazol Brilliant Blue R over chemical pretreated bottom ash, was investigated at initial concentration ranges from 10 to 100 mg/l at the optimum pH, and at 25°C. An increase in the percentage of adsorption with the increase in dye concentration in the solution is evident from Fig. 5a and b. Fig. 5a clearly shows that the uptake of Reactive Blue 49 by the bottom ash pretreated with H2O2 was almost 90% at low concentration and about 15% at higher concentration. Similarly, the uptake of Ramazol Brilliant Blue R by bottom ash pretreated with HCl, was 90% at low concentrations and about 50% at higher concentration. For the adsorption of Reactive Blue 49, the maximum uptake was reached in a dye concentration range of 15-25 mg/l. The uptake decreased when dye concentration was higher than 25 mg/l, and stayed constant about 0.08 mg/g at dye
concentration of 50 mg/l. For the adsorption of the Ramazol Brilliant Blue R, the uptake constantly increased, and reached a maximum uptake of 0.55 mg/g adsorbent, at 100 mg/l dye concentration. In both cases, the uptake percentage decreased as the initial concentration increased, and reached the equilibrium at the higher concentration.

![Graphs](image1.png)

Fig. 5. Effect of initial dye concentration on (a) adsorption of Reactive Blue 49 by H$_2$O$_2$ pretreated bottom ash (particle size < 0.5 mm, adsorbent dose = 10 g in 500 ml solution) at 25 °C and pH 2.0, contact time = 15 hours. (b) adsorption of Ramazol Brilliant Blue R by HCl pretreated bottom ash (Particle size = 0.5-1.0, mm., absorbent dose = 5 g in 50 ml solution) at 25 °C, and pH 3.0, contact time = 24 hour.

3.6. Adsorption Isotherms

3.6.1. Langmuir’s Adsorption Isotherm Model

Langmuir adsorption model is based on the physical hypothesis that there is no interaction between adsorbed molecules and the adsorption energy is distributed homogeneously over the entire coverage surface. It is the most widely used two-parameter equation, commonly expressed as [5, 6]

\[
\frac{C_e}{q_e} = \frac{C_e}{Q_0} + \frac{1}{bQ_0}
\]

Where, $q_e$ and $C_e$ are defined as the amount of dye adsorbed (mg/g) and equilibrium dye concentration (mg/l), respectively. $b$ is a direct measure of the intensity of the sorption (l/mg), and $Q_0$ is a constant related to the maximum adsorption capacity (mg/g). The constants $Q_0$ and $b$ are determined from the intercept and slope of the linear plots of the experimental data of $C_e/q_e$ versus $C_e$, respectively. The Langmuir theory assumes that adsorption takes place at specific homogenous sites within the adsorbent and that once a dyestuff molecule occupies a site, no further adsorption can take place at that site.

For the adsorption of the Ramazol Brilliant Blue R over bottom ash pretreated with 1 N HCl, the equilibrium data from Figure 5b were correlated with the Langmuir’s isotherm. The plot of $C_e/q_e$ versus $C_e$ is shown in Figure 6a, gives a straight line with correlation coefficient ($r^2$) of 0.987. Thereby, it confirms that the Langmuir isotherm is followed in the adsorption process. The values of calculated parameters for Langmuir are $b = 0.1536$ l/mg , and $Q_0 = 0.4455$ mg/g.

3.6.2. Freundlich’s Adsorption Isotherm Model

The Freundlich model assumes a heterogeneous adsorption surface having unequally available sites with different energies of adsorption. The validity of Freundlich adsorption model was established using the following relation [5]:

\[
\log q_e = \log K_f + \frac{1}{n} \log C_e
\]
\[ \log q_e = \log K_f + \frac{1}{n} \log C_e \]  

(2)

Where \( q_e \) is the amount of dye adsorbed per unit mass of adsorbent (mg/g), \( C_e \) is the equilibrium concentration of dye in solution (mg/l), \( K_f \) and \( n \) are Freundlich constants. \( K_f \) can be defined as the adsorption or distribution coefficient and represents the amount of dye adsorbed on an adsorbent for a unit equilibrium concentration; (mg/g) \((l/mg)^{1/n}\). A plot of \( \log q_e \) versus \( \log C_e \) enables the constants \( K_f \) and \( 1/n \) to be determined from the intercept and slope of the linear regression.

The equilibrium data shown in Figure 5b, which is the equilibrium adsorption of Ramazol Brilliant Blue R on the bottom ash pretreated with 1 N HCl, were correlated with Freundlich isotherm. The plot of \( \log q_e \) versus \( \log C_e \) gives a straight line with the correlation coefficient of 0.9643. The \( K_f \) and \( n \) determined from the linear regression equal to 0.1131 (mg/g)(l/mg)^{1/2.977} and 2.977, respectively. The adsorption of Ramazol Brilliant Blue R can be best described by both Freundlich and Langmuir isotherms, since the correlation coefficients from the linear regressions of these two models are not significantly different.

\[ \frac{dq}{dt} = k_1(q_e - q) \]  

(3)

Where \( q \) is the amount of dye adsorbed per unit mass of adsorbent at time \( t \), \( q_e \) is the equilibrium dye uptake, and \( k_1 \) is the pseudo first order rate constant.

\[ \frac{dq}{dt} = k_2(q_e - q)^2 \]  

(4)

Where \( k_2 \) is the pseudo second order rate constant.
\[
\frac{dq}{dt} = ae^{-bq}
\]  

(5)

Where ‘a’ and ‘b’ are constants and represent the initial adsorption rate and the surface coverage, respectively. The parameters of these models obtained from a linear least square regression using the experimental data in section 3.4 are shown in Table 2.

<table>
<thead>
<tr>
<th>Systems</th>
<th>1st Order</th>
<th>2nd Order</th>
<th>Elovich</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(q_e) (Exp.)</td>
<td>(k_1) (min(^{-1}))</td>
<td>(q_e) (mg/g)</td>
</tr>
<tr>
<td>Ramazol Brilliant Blue R</td>
<td>0.5560</td>
<td>0.0013</td>
<td>0.3884</td>
</tr>
<tr>
<td>10 g/50 ml</td>
<td>0.3997</td>
<td>0.0032</td>
<td>0.3568</td>
</tr>
<tr>
<td>15 g/50 ml</td>
<td>0.2840</td>
<td>0.0053</td>
<td>0.2100</td>
</tr>
<tr>
<td>Reactive Blue 49</td>
<td>0.0132</td>
<td>0.0043</td>
<td>0.0077</td>
</tr>
</tbody>
</table>

The comparison of experimental q and predicted q values from the pseudo first order, pseudo second order and Elovich’s equations, are presented in Figure 7. As shown on figure 7, the adsorption of Brilliant Blue R and Reactive Blue 49 on pretreated coal bottom ash is best described by pseudo second order model. However, when the dose of the adsorbent changed to 5 g and 10 g per 50 ml solution for Brilliant Blue R case, the predicted q values form the pseudo second order model are close to the experimental values near the end of adsorption process. While, those from Elovich’s model are close to the experimental values at the beginning of the adsorption process (not shown in figure).

![Fig. 7](image_url)

4. Conclusion

The present study showed that bottom ash can be used as the adsorbents for removal of reactive dye from aqueous solution, although it’s not as efficient as the high price commercial activated carbon. The chemical pretreatment can change the surface chemistry which will facilitate the adsorption process, but does not improve the porous properties of the adsorbent. The surface areas of the bottom ashes are very low compared with the activated carbon, so the adsorption process rely only on the interaction between adsorbent surface charges and the charges on the dye molecule. The bottom ash pretreated with 1 N HCl, 1 N HNO\(_3\), and 30% H\(_2\)O\(_2\) can adsorb Reactive Blue 49 in the same extent. However, the bottom ash pretreated with HCl gave higher adsorption capacity. The optimum pH for the adsorption of Reactive blue 19 and Ramazol Brilliant Blue R on pretreated bottom ash was found to be 2
and 3, respectively. The smaller particle size of adsorbent showed better performance for dye adsorption, but the separation of the bottom ash from the water should also be considered in selection of the size of the adsorbent. The equilibrium adsorption of Ramazol Brilliant Blue R was best fitted with both Langmuir and Freundlich isotherms. The adsorption kinetics of both dyes were best fitted with pseudo second order model.

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References


