Modified Sugarcane Bagasse as Adsorbent for Removal Cutting Fluid Wastewater

Thitima Srilajan, Toungrat Janpattanapong, and Kowit Piyamongkala

Abstract—The modified sugarcane bagasse was used as an adsorbent to remove cutting fluid from the wastewater in the batch adsorption system. The effect of initial concentration of cutting fluid and the agitation speed were investigated. The kinetics and mechanism of adsorption of cutting fluid were studied. It was found that the trend of increase in the initial cutting fluid concentration from 3.0–10.0 %w/v and the agitation speed from 60–120 rpm increased the adsorption capacity from 1869.1–4761.9 and 4317.9–4761.9 mg/g, respectively. The adsorption capacity of cutting fluid wastewater was 300.2 mg/g. The pseudo-first order and pseudo-second order were employed to evaluate the kinetics model. It was found that the adsorption behavior was fit with pseudo-second order model rather than pseudo-first order model. The mechanism of cutting fluid adsorption onto modified sugarcane bagasse occurred in 2 steps. The significant uptake of cutting fluid was demonstrated by FT-IR spectroscopy.

Keywords—Adsorption, Cutting fluid, Modified sugarcane bagasse

I. INTRODUCTION

Cutting fluids are used for lubricating and cooling of metal cutting operations by reducing friction between tool and piece-work and carrying away heat [1]. The cutting fluid prevents fine chip of metal from catching on the tools and piece-work. Other functions of cutting fluid are to prevent wear on the tools and reduce energy requirements. Four major classes of cutting fluid in the mechanical processes are straight oil, soluble oil, synthetic oil and semi-synthetic oil [2].

In most mechanical processes involving a cutting operation, spent cutting fluid was discharged to the wastewater treatment plant of manufacturers. The emulsion oily wastewater was treated by chemical [3], flotation [4], biological [5] or thermal processes [6].

The adsorption is one process used to treat cutting fluid wastewater. The advantage of this process is operation at normal temperature and pressure. It did not require adding chemicals for de-emulsion and cleaning adsorbent. In addition, then is no problem of floatation of emulsion and clog up at the surface of the adsorbent. It was found that the literatures on reducing cutting fluid wastewater for adsorption process onto adsorbent were a very small. Mathavan and Raraghavan [7] described that cutting oil, refinery oil, crude oil and mineral oil could be adsorbed by peat. Solisio et al. [8] used mixture of Ca and Mg oxides as adsorbent treated exhausted oils. Cambiella et al. [9] used sawdust treat oil in water emulsion. Piyamongkala et al. used modified chitosan removal cutting fluid wastewater [10].

In this paper, the interests of the study were treatment of cutting fluid by adsorption onto modified sugarcane bagasse with aluminium sulfate for reduces contamination of emulsion oil into a stream and also to study kinetic adsorption of cutting fluid onto modified sugarcane bagasse.

II. MATERIALS AND METHODS

A. Adsorbate

Cutting fluid used in this study was commercial grade purchased from Rifle Brand Trade Mark, Thailand. The cutting fluid was loaded in distilled water, and then was stirred at 1,200 rpm for 10 min by motor stirrer to form emulsion. After that the emulsion was left for 10 min. To investigate an adsorption of cutting fluid on the adsorbents, the cutting fluid wastewater from Department of Tool and Dies Engineering Technology, College of Industrial Technology, King Mongkut’s University of Technology North Bangkok was used.

B. Adsorbent

The sugarcane bagasse used in the present investigation was obtained from sugarcane refinery of Thailand. The wet sugarcane bagasse was reduced moisture by sunlight for a period of 48 h, and then was dried by oven at 130 °C for a period of 3 h to obtained dry sugarcane bagasse, and then screened through a sive 10 mesh to get granular dry sugarcane bagasse. The pore volume, pore diameter and surface area of dry sugarcane bagasse as calculated by BET method were 4.3×10⁻³ m³/g, 39.8 nm and 4.3×10⁻¹ m²/g, respectively. The modified sugarcane bagasse was prepared from granular dry sugarcane bagasse amount 50 g reacted with aluminium sulfate (stirred at 500 rpm of 6 h) filtrated with filter paper No 1 and then collected the part to stuck on filter paper for dry by oven at 130 °C for a period of 2 h to obtain modified sugarcane bagasse as adsorbent. The pore volume, pore diameter and surface area of modified sugarcane bagasse were 3.3×10⁻³ m³/g, 70.7 nm and 1.9×10⁻¹ m²/g, respectively.

C. Adsorption Experiment

The batch sorption experiments were carried out in erlenmeyer flasks. The adsorbent amount 2.0 g was added in

Thitima Srilajan, Toungrat Janpattanapong and Kowit Piyamongkala are with the Department of Industrial Chemistry, Faculty of Applied Science, King Mongkut’s University of Technology North Bangkok, Bangsue, CO 10800 Thailand (corresponding author’s phone: +66 (0) 25552000 Ext. 4812; e-mail: kwt@kmutnb.ac.th).

http://dx.doi.org/10.15242/IIE.E1214006
flasks. The initial cutting fluid concentration was studied in the range of 3.0, 5.0, 7.0 and 10.0 %w/v. The mixture was shaken at 120 rpm. The effect of speed of agitation was studied in the range of 60, 90 and 120 rpm. The cutting fluid was analyzed by a visible spectrophotometer at wavelength 395 nm. The percent adsorption and adsorption capacity at initial and different time intervals were calculated according to (1) and (2), respectively.

\[
\text{Percent adsorption} = \left(\frac{C_0 - C_t}{C_0}\right) \times 100
\]  

(1)

\[
q_{\text{c, exp}} = \left(\frac{(C_0 - C_t) \times V}{W}\right)
\]  

(2)

Where \(C_0\) is initial cutting fluid concentration (mg/L), \(C_t\) is concentration of cutting fluid at time (mg/L), \(q_{\text{c, exp}}\) is adsorption capacity of cutting fluid at time from experiment (mg/g), \(V\) is volume of cutting fluid (L) and \(W\) is weight of adsorbent (g).

D. FT-IR Spectra

The FT-IR spectra of cutting fluid, sugarcane bagasse, modified sugarcane bagasse before and after adsorption cutting fluid were measured by FT-IR spectrophotometer in the range 4000–400 cm\(^{-1}\). The adsorbents were powdered and mixed with potassium bromide and then pressed into pellet under pressure. An average of 10 scans was made for each sample at a resolution of 4 cm\(^{-1}\).

III. RESULT AND DISCUSSION

A. Effect of Initial Cutting Fluid Concentration

The effect of initial cutting fluid concentration on kinetic of adsorption is shown in Figure 1. It was found that, increase in the initial cutting fluid concentration led to an increase in the adsorption capacity. The adsorption capacity was vary rapid at the initial period of contact time and even reached equilibrium when the adsorption was in progress. In the first 2 min, the amounts of adsorption capacity were 1818.0–4000.0 mg/g, when initial cutting fluid concentration increased from 3.0–10.0 %w/v, respectively. At equilibrium occurred at 8 min, the adsorption capacity increased to 1869.1–4761.9 mg/g, respectively. An increasing initial concentration increased adsorption capacity due to the high concentration gradient in the beginning of adsorption which represents a high driving force for the transfer of adsorbate from solution to the surface of adsorbent [11].

B. Effect of Agitation Speed

The results of adsorption capacity of modified sugarcane bagasse for adsorbed cutting fluid, when various speeds of agitation is shown in Figure 2. It was found that, increase in the speed of agitation from 60–120 rpm leads to an increase in the adsorption capacity from 4317.9–4761.9 mg/g, respectively. This effect can be attributed to the strong turbulence and the very small thickness around the adsorbent in the boundary layer as a result of a reduction in the boundary layer resistance and an induction in the mobility of system [12].

Fig. 1 Adsorption capacity of cutting fluid onto modified sugarcane bagasse at concentration: ♦ 3.0, ■ 5.0, ▲ 7.0 and ● 10.0 %w/v

Fig. 2 Adsorption capacity of cutting fluid onto modified sugarcane bagasse at agitation speed: ▲ 60, ■ 90, ● 120 rpm and ♦ cutting fluid wastewater

C. Kinetic Adsorption Model

In an attempt to present the kinetic equation representing the adsorption of cutting fluid onto modified sugarcane bagasse, three kinds of kinetic models were used to test the experimental data. These are pseudo-first order, pseudo-second order and intraparticle diffusion [13].

The pseudo-first order equation is the most popular kinetics equation. The form is shown in (3).

\[
\frac{dq_{\text{c, cal}}}{dt} = k_1(q_{\text{c, exp}} - q_{\text{t, exp}})
\]  

(3)

After definite integration by applying conditions where \(q_t = 0\) at \(t = 0\) and \(q_t = q_c\) at \(t = t\), equation (3) becomes the following linear and non-linear according to (4) and (5), respectively.

\[
\log (q_{\text{c, exp}} - q_{\text{t, exp}}) = \log q_{\text{c, cal}} - \frac{k_1 t}{2.303}
\]  

(4)

\[
q_{\text{t, cal}} = q_{\text{c, cal}} (1 - e^{-k_1 t})
\]  

(5)
where $q_{t,\text{cal}}$ is adsorption capacity of cutting fluid at time from calculation (mg/g), $q_{t,\text{exp}}$ is adsorption capacity of cutting fluid at equilibrium from experiment (mg/g), $q_{e,\text{cal}}$ is adsorption capacity of cutting fluid at equilibrium from calculation (mg/g), $k_1$ is rate constant of pseudo-first order (min$^{-1}$) and $t$ is time use in adsorption (min).

The plots of $\log (q_{t,\text{exp}} - q_{t,\text{exp}})$ against time ($t$) for the effects of initial cutting fluid concentration and agitation speed onto modified sugarcane bagasse are not shown. The $k_1$, $R^2$, $q_{e,\text{cal}}$ and $q_{e,\text{exp}}$ values are shown in Table 1 and Table 2. It was found that the $R^2$ for the pseudo-first order was less than 0.9029. The adsorption capacity from experimental and calculate does not fit reasonable values. This suggests that the adsorption of cutting fluid onto modified sugarcane bagasse is not a pseudo-first order.

The pseudo-second order equation is shown in (6).

$$\frac{d q_{t,\text{cal}}}{dt} = k_2(q_{e,\text{exp}} - q_{t,\text{exp}})^2$$

(6)

After definite integration by applying conditions where $q_t = 0$ at $t = 0$ and $q_t = q_e$ at $t = t$, equation (6) becomes the following linear and non-linear according to (7) and (8), respectively.

$$\frac{t}{q_{t,\text{exp}}} = \frac{1}{k_2q_{e,\text{cal}}} + \frac{t}{q_{e,\text{cal}}}$$

(7)

$$q_{t,\text{cal}} = \frac{q_{e,\text{cal}}^2k_2}{1 + q_{e,\text{cal}}k_2t}$$

(8)

where, $k_2$ is rate constant of pseudo-second order (g/mg-min).

The plots of $t/q_{t,\text{exp}}$ against for the effects of the initial cutting fluid concentration and the agitation speed onto modified sugarcane bagasse are shown in Figure 3 and Figure 4, respectively. The straight line in plot $t/q_{t,\text{exp}}$ versus $t$ proved to be a good agreement of experimental data with the pseudo-second order. From these Figures, the values of $q_{e,\text{cal}}$ and $k_2$ were determined from the slope and intercept of the plots, respectively. The $k_2$, $R^2$, $q_{e,\text{cal}}$ and $q_{e,\text{exp}}$ values are shown in Table 1 and Table 2. It was found that the $R^2$ for the pseudo-second order was fitted with the adsorption process. The adsorption capacity obtain from calculate accords very well with the adsorption capacity from experiment. This suggests that the adsorption of cutting fluid onto modified sugarcane bagasse is a pseudo-second order, it predicts the behavior over the whole range of studies which support the validity, and is in agreement with chemisorptions being the rate controlling [14].

The intraparticle diffusion rate equation can be written as follows to (9).

$$q_{t,\text{exp}} = k_{i,d}t^{0.5}$$

(9)

where, $k_{i,d}$ is rate constant of intraparticle diffusion (mg/g/min$^{0.5}$).
Fig. 5 Intraparticle kinetic adsorption onto modified sugarcane bagasse at initial cutting fluid concentration: ● 3.0, ■ 5.0, ▲ 7.0, ● 10.0 %w/v and × cutting fluid wastewater

Fig. 6 Intraparticle kinetic adsorption onto modified sugarcane bagasse at agitation speed: ▲ 60, ■ 90 and ● 120 rpm

D. FT-IR Spectra

Figure 7 (a) and (b) show FT-IR spectra of modified sugarcane bagasse before adsorption cutting fluid and sugarcane bagasse, respectively. It was found that the C-O-C asymmetrical stretching at 1162 cm\(^{-1}\). Figure 7 (c) shows FT-IR spectra of cutting fluid. It was found that the main component of cutting fluid. The alkane appears at 2925 and 2855 cm\(^{-1}\), methylene and methyl appears at 1465 and 1375 cm\(^{-1}\). The long chain of methylene group, which has more than four carbon atoms appears at 720 cm\(^{-1}\) [15]. Figure 7 (d) shows the spectra of modified sugarcane bagasse after adsorption cutting fluid. It can be found that alkane appears at 2927 and 2869 cm\(^{-1}\), at 1468 cm\(^{-1}\) for methylene and at 1379 cm\(^{-1}\) for methyl. The appearance of alkane, methylene and methyl groups onto modified sugarcane bagasse after adsorption cutting fluid demonstrated that the adsorption of cutting fluid occurred onto modified sugarcane bagasse.

![FT-IR Spectra](image)

Table I: Rate Constant and Intraparticle Diffusion for Initial Concentration of Cutting Fluid Adsorption Onto Modified Sugarcane Bagasse

<table>
<thead>
<tr>
<th>Concentration (%w/v)</th>
<th>qe, exp</th>
<th>Pseudo – first order</th>
<th>Pseudo – second order</th>
<th>Intraparticle diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>k(_1)</td>
<td>qe(cal)</td>
<td>R(^2)</td>
</tr>
<tr>
<td>3.0</td>
<td>1869.1</td>
<td>-0.081</td>
<td>25.8</td>
<td>0.4621</td>
</tr>
<tr>
<td>5.0</td>
<td>2804.8</td>
<td>-0.202</td>
<td>128.8</td>
<td>0.5522</td>
</tr>
<tr>
<td>7.0</td>
<td>3594.7</td>
<td>-0.253</td>
<td>691.7</td>
<td>0.7354</td>
</tr>
<tr>
<td>10.0</td>
<td>4761.9</td>
<td>-0.115</td>
<td>696.9</td>
<td>0.8572</td>
</tr>
<tr>
<td>Wastewater</td>
<td>300.2</td>
<td>-0.083</td>
<td>128.7</td>
<td>0.9029</td>
</tr>
</tbody>
</table>

Table II: Rate Constant and Intraparticle Diffusion for Agitation Speed of Cutting Fluid Adsorption Onto Modified Sugarcane Bagasse

<table>
<thead>
<tr>
<th>Agitation speed (rpm)</th>
<th>qe, exp</th>
<th>Pseudo – first order</th>
<th>Pseudo – second order</th>
<th>Intraparticle diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>k(_1)</td>
<td>qe(cal)</td>
<td>R(^2)</td>
</tr>
<tr>
<td>60</td>
<td>4317.9</td>
<td>-0.44</td>
<td>1504.9</td>
<td>0.6790</td>
</tr>
<tr>
<td>90</td>
<td>4461.1</td>
<td>-0.038</td>
<td>1240.2</td>
<td>0.6047</td>
</tr>
<tr>
<td>120</td>
<td>4761.9</td>
<td>-0.115</td>
<td>696.9</td>
<td>0.8572</td>
</tr>
</tbody>
</table>

http://dx.doi.org/10.15242/IIE.E1214006 164
IV. CONCLUSION

The adsorption capacity of cutting fluid wastewater onto modified sugarcane bagasse and agitation speed 120 rpm was 300.2 mg/g. The kinetic of adsorption was pseudo-second model. The mechanism of adsorption involved in 2 steps. The FT-IR can be proved the cutting fluid adsorption onto modified sugarcane bagasse.

ACKNOWLEDGMENT

This research was funded by King Mongkut’s University of Technology North Bangkok. Contract no. KMUTNB-GEN-57-11.

REFERENCES


