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บทความวิจัย

การศึกษาสมดุลและการออกแบบการดูดซับน้ำมันหล่อเย็นโดยชานอ้อยและชานอ้อยดัดแปร

วรัญญา แช่มปรีชา อัญธิกา ประนัดทา และ โกวิทย์ ปิยะมังคลา*
ภาควิชาเคมีอุตสาหกรรม คณะวิทยาศาสตร์ประยุกต์ มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าพระนครเหนือ

* ผู้นิพนธ์ประสานงาน โทรศัพท์ 08-9007-8906 อีเมล: kowit.p@sci.kmutnb.ac.th

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รับเมื่อ 3 ธันวาคม 2558 ตอบรับเมื่อ 23 มีนาคม 2559 เผยแพร่ออนไลน์ 19 ตุลาคม 2559

บทคัดย่อ

ชานอ้อยและชานอ้อยดัดแปรด้วยกรดฟอสฟอริกความเข้มข้น 1.0 โมลาร์ นำมาใช้เป็นตัวดูดซับน้ำมันหล่อเย็นชนิดผสมน้ำ การทดลองทำเป็นแบบแบตซ์ ศึกษาผลปริมาณตัวดูดซับและความเข้มข้นเริ่มต้นของน้ำมันหล่อเย็นชนิดผสมน้ำ ประจุที่ผิวเป็นศูนย์ของชานอ้อยและชานอ้อยดัดแปรมีค่าเท่ากับ pH 5.2 และ 2.2 ตามลำดับ ร้อยละการดูดซับและความสามารถในการดูดซับน้ำมันหล่อเย็นชนิดผสมน้ำเพิ่มสูงขึ้นด้วยการเพิ่มปริมาณตัวดูดซับและความเข้มข้นเริ่มต้นของน้ำมันหล่อเย็นชนิดผสมน้ำ ตามลำดับ ผลการทดลองนำชานอ้อย และชานอ้อยดัดแปรปริมาณ 5 กรัม ดูดซับน้ำมันหล่อเย็นชนิดผสมน้ำความเข้มข้นเริ่มต้นร้อยละ 5.0 โดยน้ำหนักต่อปริมาตร พบว่ามีความสามารถในการดูดซับเท่ากับ 62.4 และ 519.7 มิลลิกรัมต่อกรัม ตามลำดับ สมการแลงเมียร์และฟรุนดิชนำมาใช้อธิบายสมดุลการดูดซับน้ำมันหล่อเย็นชนิดผสมน้ำ พบว่าตัวดูดซับทั้งสองชนิดมีความสอดคล้องกับสมการฟรุนดิช การดูดซับแบบขั้นตอนเดียวของตัวดูดซับทั้งสองชนิดมีการออกแบบโดยใช้สมการฟรุนดิช การดูดซับน้ำมันหล่อเย็นบนตัวดูดซับยืนยันได้จากผลฟูเรียร์ทรานฟอร์มอินฟราเรดสเปกโทรสโกปี

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Research Article

Equilibrium and Batch Design Studies for Cutting Fluid Adsorption onto Sugarcane Bagasse and Modified Sugarcane Bagasse

Waranya Champreecha, Antika Pranudta and Kowit Piyamongkala*
Department of Industrial Chemistry, Faculty of Applied Science, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand

* Corresponding Author, Tel. 08-9007-8906, E-mail: kowit.p@sci.kmutnb.ac.th

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Abstract

The Sugarcane Bagasse (SB) and Modified Sugarcane Bagasse (MSB) with 1.0 M H_3PO_4 were used as adsorbents for removal of the water-soluble cutting fluid. The effects on the amount of adsorbents and initial concentration of the cutting fluid were thoroughly investigated in batch adsorption system. The point of zero charge of sugarcane bagasse and modified sugarcane bagasse as adsorbents were pH 5.2 and 2.2 respectively. The percent adsorption and adsorption capacity increased with increasing amount of adsorbents and initial concentration of cutting fluid, respectively. The experimental results showed that adsorption capacity onto 5.0 g of sugarcane bagasse and modified sugarcane bagasse for cutting fluid initial concentration 5.0 % w/v were 62.4 and 519.7 mg/g, respectively. The Langmuir and Freundlich adsorption isotherms were applied to describe the cutting fluid uptake, which could be described by Freundlich adsorption isotherm onto both adsorbents. Single-state batch adsorption design of cutting fluid onto both adsorbents has been studied based on the Freundlich isotherm equation. The significant uptake of cutting fluid was demonstrated by FT-IR spectroscopy.

Keywords: Adsorption, Cutting Fluid, Sugarcane Bagasse, Modified Sugarcane Bagasse

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1. Introduction

Cutting fluids, also called metal working fluid, cutting oil or soluble oil, are used in the production process in section of machining operation including turning, drilling, grinding and milling. The functions of cutting fluids are lubricating, dissipating heat and flushing fin-chip [1]. Cutting fluids play a significant role in extending tool life and shaping quality of work. Two types of cutting fluids used in machining operation are oil-based and water- based. The oil-based or straight oil of cutting fluid are animal, marine, vegetable and mineral oils. The water-based is something mixed with clear water (tap water, distilled water) to form oil-in-water emulsion. The synthetic, semi- synthetic and soluble oils are water-based cutting fluid.

After the use of cutting fluid in machining operation, it loses its lubricating property due to thermal degradation, which is generated due to heat between the face of tool and metal being cut. It contains microorganisms, biocides and harmful products. The separation treatment methods of cutting fluid included gravity settling, flotation, micro-filtration and adsorption [2].

The adsorption is one process used to treat cutting fluid. 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 literature on reducing cutting fluid for adsorption process onto adsorbents were a very little. Mathavan and Viraraghavan [3] described that cutting oil, refinery oil, crude oil and mineral oil could be adsorbed by peat. Solisio et al. [4] used mixture of Ca and Mg oxides as adsorbent treated exhausted oils. Cambiella et al. [5] used sawdust treat oil in water emulsion. Piyamongkala *et al*. [1] and Kittithawornkul *et al*. [6] used modified chitosan and synthetic acid soil for removal cutting fluid, respectively.

Sugar cane production and sugar industry have a very significant role in Thailand's agriculture industry. In Thailand, 106,000,000 tonnes of sugar cane were produced in 2014/2015 [7]. Sugar cane bagasse, about 30 % of sugar cane, is the by-product of sugar production and large quantities of bagasse are obtained after sugar production. It is a valuable solid fuel to be combusted in steam boilers. Sugarcane bagasse contains cellulose 46%, hemicellulose 24.5%, lignin 19.9%, fat and waxes 3.5%, ash 2.4% silica 2.0% and other element 1.7% [8]. It is used as an adsorbent for the removal of methyl red dye [9], heavy metals such copper, cadmium and lead [10] or petroleum hydrocarbons [11].

The objectives of this paper are 1) to study the feasibility of using modified sugarcane bagasse as an adsorbent for the removal of cutting fluid, 2) to determine the various parameters affecting sorption such as adsorbent dose and initial cutting fluid concentration, 3) to evaluate Langmuir and Freundlich isotherms and 4) to predict amount of adsorbents to volume of cutting fluid.

2. Experimental

2.1 Adsorbate

Cutting fluid (CF^-) 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 minutes by motor stirrer (Janke & Kunkel; Model RW 20) to form emulsion. After that, the emulsion was left for 10 minutes and then measured the acid-base (Eutech; Model pH 510) conditions of cutting fluid which was about pH 8.9.

2.2 Preparation of Adsorbent

The sugarcane bagasse used in the present study was obtained from sugarcane refinery in Nakhon Sawan province of Thailand. The wet sugarcane bagasse was kept in the sunlight for a period of 48 hrs to reduce the moisture, and then was dried using oven (Binder; Model FD 53) at 130°C for a period of 3 hrs to obtain dry sugarcane bagasse, and then screened through a sieve 10 mesh (size 1.7 mm) to get granular dry sugarcane bagasse (SB). The pore volume, pore diameter and surface area of sugarcane bagasse as calculated by BET method (BEL JAPAN; Model Belsorp-mini) was 5.2×10^{-3} m^3/g, 40.1 nm and 5.2×10^{-1} m^2/g, respectively. The modified sugarcane bagasse was prepared from granular dry sugarcane bagasse amount 50 g reacted with 1.0 M 500 cm^3 of phosphoric acid (stirred at 500 rpm for 6 hrs) filtrated with filter paper No 1 (Whatman) and then collected the part stucked on filter paper to dry by sunlight for a period of 48 hrs to obtain modified sugarcane bagasse (MSB) as adsorbent. The pore volume, pore diameter and surface area of modified sugarcane bagasse was 4.8×10^{-3} m^3/g, 759.9 nm and 2.5×10^{-2} m^2/g, respectively. This produced a uniform material for the complete set of adsorption which was stored in an air-tight plastic container for all investigations.

2.3. Point of Zero Charge of Adsorbent

The pH_{pzc} of sugarcane bagasse and modified sugarcane bagasse were measured by preparing a solution of 0.1 M sodium chloride (BDH) in preboiled distilled water in order to eliminate carbon dioxide. Each 100 cm^3 of sodium chloride solution in 250 cm^3 of Erlenmeyer flasks were adjusted to a value between pH 1.0–11.0 by adding either diluted 0.1 M hydrochloric acid (J.T.Baker) or sodium hydroxide (BDH). The sugarcane bagasse and modified sugarcane bagasse 0.1 g were added to the solution. All the flasks were sealed by paraffin to avoid contact with air and shaken by an orbital shaker (UMAC Scientific; Model UM-S6O) at room temperature for 48 hrs. The samples were filtered through filter paper No. 1. The final pH was measured and plotted against the initial pH. The pH at which the curve crossed the line, $pH_{initial} = pH_{final}$ was taken as the point of zero charge.

2.4 Adsorption Experiment

The batch sorption experiments were carried out in 250 cm^3 of Erlenmeyer flasks. The adsorbent amount 0.5–5.0 g and 100 cm^3 of cutting fluid (emulsion 0.5–5.0 % w/v) were added in flasks. The mixture was shaken at 120 rpm and 31°C. At equilibrium of adsorption, the emulsion was taken to determine the residual concentration of cutting fluid. The initial and residual concentration of cutting fluid was analyzed by a visible spectrophotometer (Thermo electron; Model Spectronic Genesys 20) at wavelength 395 nm. The percent adsorption and adsorption capacity at equilibrium of adsorption was calculated according to Eq. (1) and (2), respectively.

$$\text{Percent adsorption} = \left(\frac{C_0 - C_e}{C_0}\right)\times 100 \quad (1)$$

$$q_e = \left(\frac{(C_0 - C_e)\times V}{W}\right) \quad (2)$$

where C_0 is initial concentration of cutting fluid (mg/L), C_e is concentration of cutting fluid at equilibrium (mg/L), q_e is adsorption capacity at equilibrium (mg/g), V is volume of cutting fluid (L) and W is weight of adsorbent (g).

2.5 FT-IR Spectra

The FT-IR spectra of cutting fluid, modified sugarcane bagasse before and after adsorption were measured by FT-IR spectrophotometer (Pekin-Elmer Model 2000) in the range 4000–400 cm^{-1}. The adsorbents were powdered and mixed with potassium bromide (BDH) and then pressed into pellet under pressure. An average of 10 scans was made for each sample at a resolution of 4 cm^{-1}.

3. Results and Discussion

3.1 Point of Zero Charge

The comprehensive influence of all functional groups determines pH$_{pzc}$, the pH at which the net charge on the surface adsorbent is zero. Thus, depending on the pH of the solution, their surfaces might be positively charge, negatively charge or neutral when the solution pH is below, above or equal to the pH$_{pzc}$, respectively [12]. At pH < pH$_{pzc}$, the surface of adsorbent has a net positive charge, whereas at pH > pH$_{pzc}$, the surface of adsorbent has a net negative charge. Figure 1 shows the pH drift test, which has the pH$_{pzc}$ values of 5.2 and 2.2 for sugarcane bagasse and modified sugarcane bagasse, respectively. As a result, the pH$_{pzc}$ of modified sugarcane bagasse shifted from 5.2 to 2.2. Such charge properties of modified sugarcane bagasse surface would be expected to have a dramatic effect on the adsorption of cutting fluid.

3.2 Effect of Adsorbent Dosage

The effect of sugarcane bagasse and modified sugarcane bagasse dosage from 0.5–5.0 g for adsorption of the cutting fluid is shown in Figure 2. The percent adsorption increased from 1.0–11.9% and 3.0–80.2%, respectively. It was noticed that when the amount of adsorbents increased, the percent adsorption of the adsorbents increased as well. An increase in the percent adsorption with the adsorbent dosage can be attributed to greater surface area and the availability of more adsorption sites of adsorbent [13].

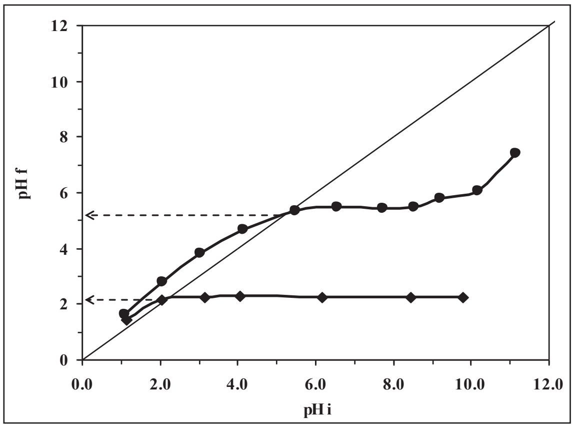

Figure 1 Point of zero charge: ● SB and ♦ MSB.

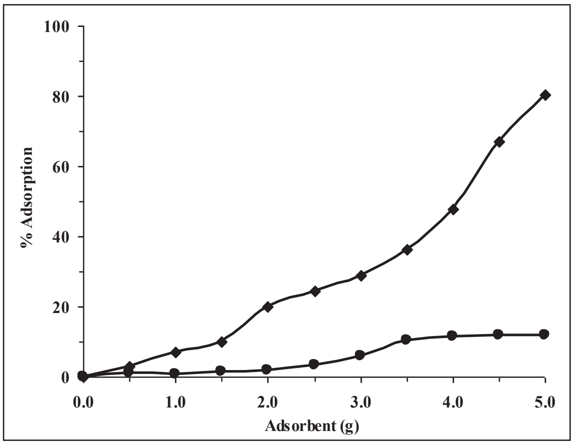

Figure 2 Dosage of adsorbents to percent adsorption of cutting fluid: ● SB and ♦ MSB.

Additives within the cutting fluid include corrosion inhibition, lubrication, emulsification, microbial control, defoaming, pH buffering, wetting, coupling and dispersing. Most of the additives used are organic chemicals that are anionic or nonionic in charge such as amine, fatty acid, ester, sulfonates, soap, borate, phosphate [14]. The point of zero charge of cutting fluid is obtained at pH 3.2 [1]. The cutting fluid has negative surface charges when pH is above 3.2 but has positive surface charges when pH is below 3.2.

Sugarcane bagasse is a plant biomass. It contains complex organic components such as protein, lipid and carbohydrate. The possible sites on sugarcane bagasse adsorbent for specific adsorption include hydroxyl (–OH) and carboxylic (–COOH) functional groups [15]. These functional groups dissociated according to Eq. (3)–(4). Sugarcane bagasse shows positive and negative charges according to Eq. (5)–(6) and Eq. (7)–(8), respectively. While, sugarcane bagasse shows less positive charge that is able to adsorb the cutting fluid as shown in the following Eq. (9)–(10)

$$\text{SB–OH} \rightleftharpoons \text{SB–O}^- + \text{H}^+ \quad (3)$$

$$\text{SB–COOH} \rightleftharpoons \text{SB–COO}^- + \text{H}^+ \quad (4)$$

$$\text{SB–OH} + \text{H}^+ \rightleftharpoons \text{SB–OH}_2^+ \quad (5)$$

$$\text{SB–COOH} + \text{H}^+ \rightleftharpoons \text{SB–COOH}_2^+ \quad (6)$$

$$\text{SB–OH} + \text{OH}^- \rightleftharpoons \text{SB–O}^- + \text{H}_2\text{O} \quad (7)$$

$$\text{SB–COOH} + \text{OH}^- \rightleftharpoons \text{SB–COO}^- + \text{H}_2\text{O} \quad (8)$$

$$\text{SB–OH}_2^+ + \text{CF}^- \rightleftharpoons \text{SB–OH}_2\text{CF} \quad (9)$$

$$\text{SB–COOH}_2^+ + \text{CF}^- \rightleftharpoons \text{SB–COOH}_2\text{–CF} \quad (10)$$

The surfaces of the adsorbent are expected to be positively charged which facilitate the adsorption of the negatively charged cutting fluid. The increase of the amount of adsorbent favors the surface of the adsorbent to be more positive and the percent adsorption of cutting fluid increases.

The modified sugarcane bagasse shows percent adsorption of more sugarcane bagasse due to dissociation of hydrogen ion of phosphoric acid adsorbed onto surface of adsorbent as following Eq. (11). The surface of modified sugarcane bagasse as illustrated in Eq. (12)–(13). It could destabilize the negatively charge of cutting fluid and modified sugarcane bagasse adsorbed cutting fluid by charge neutralization mechanism which identified that the pH_{pzc} of modified sugarcane bagasse was lower than sugarcane bagasse. Therefore, the modified sugarcane bagasse shows highly positive charge that it could adsorb the emulsion of cutting fluid very well according Eq. (14)–(15).

$$\text{H}_3\text{PO}_4 \rightleftharpoons \text{H}_2\text{PO}_4^- + \text{H}^+ \quad (11)$$

$$\text{SB–OH}_2^+ + \text{H}^+ \rightleftharpoons \text{MSB–OH}_3^+ \quad (12)$$

$$\text{SB–COOH}_2^+ + \text{H}^+ \rightleftharpoons \text{MSB–COOH}_3^+ \quad (13)$$

$$\text{MSB–OH}_3^+ + \text{CF}^- \rightleftharpoons \text{MSB–OH}_3\text{–CF} \quad (14)$$

$$\text{MSB–COOH}_3^+ + \text{CF}^- \rightleftharpoons \text{MSB–COOH}_3\text{–CF} \quad (15)$$

3.3 Effect of Initial Cutting Fluid Concentration

The adsorption capacity of cutting fluid of sugarcane bagasse and modified sugarcane bagasse as a function of initial cutting fluid concentration is presented in Figure 3. The equilibrium adsorption of cutting fluid on both adsorbents at 0.5–5.0 % w/v increased from 28.9–62.4 and 108.8–519.7 mg/g,

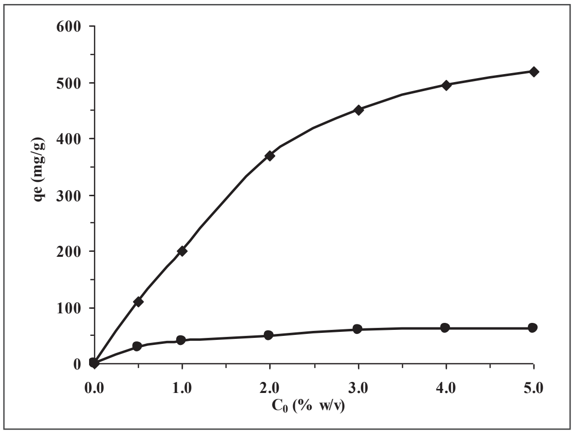

Figure 3 Adsorption capacity vary initial cutting fluid concentration: ● SB and ♦ MSB.

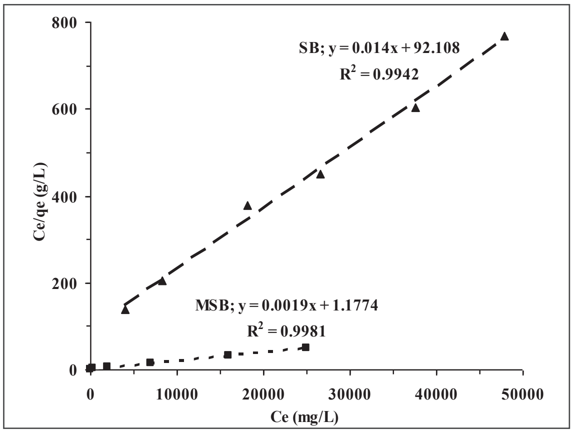

Figure 4 Langmuir isotherm of cutting fluid adsorbed onto: ▲ SB and ■ MSB.

respectively. The adsorption capacity increases with the increase in initial cutting fluid concentration due to increase in the driving force between cutting fluid emulsion and surface of adsorbent. After adsorption, cutting fluid effluent showed the acidity at pH 3–4. Such phenomena have been seen for adsorption of methylene blue onto rice husk [16].

3.4 Adsorption Isotherm Models

Adsorption isotherms were measured in order to evaluate adsorption capacity discrepancy between experimental and theoretical prediction from the equilibrium of adsorption. In addition, equation parameters and basic thermodynamic assumptions of these equilibrium models often provide some insight into both the sorption mechanisms and the surface properties and affinities of sorbents [17]. In this study, two common isotherms were used to describe the experimental adsorption data, Langmuir and Freundlich model.

Langmuir isotherm of adsorption depends on the assumption that intermolecular forces decrease rapidly with distance and consequently predicts the existence of monolayer coverage of the adsorbate at the outer surface of the adsorbent, adsorption takes place at specific homogeneous sites within the adsorbent once adsorbate occupies an site [18]. Langmuir isotherm is often used to describe adsorption of adsorbate from a liquid solution as shown in Eq. (16).

$$q_e = \frac{a_{m,L} C_e}{1 + K_L C_e} \tag{16}$$

The constants $a_{m,\,L}$ and K_L are characteristics of the Langmuir equation and can be determined from a linearized form of Eq. (16), represented by Eq. (17).

$$\frac{C_e}{q_e} = \left(\frac{K_L}{a_{m,\,L}}\right) C_e + \frac{1}{a_{m,\,L}} \tag{17}$$

where $a_{m,\,L}$ is Langmuir isotherm constant (L/g) and K_L is Langmuir constant related to the free adsorption energy (L/mg).

From the linear plot of C_e/q_e versus C_e, $a_{m,\,L}$ and K_L can be calculated from its intercept and slope, respectively. The value of correlation coefficient (R^2) shows in Figure 4 and calculation $a_{m,\,L}$ and K_L of cutting

Table 1 Langmuir and Freundlich isotherm constants of cutting fluid sorption onto SB

Concentration (% w/v)	$q_{e,\,exp}$	Langmuir Isotherm						Freundlich Isotherm				
		$a_{m,\,L}$	K_L	R^2	χ^2	R_L	$q_{e,\,cal}$	n	K_F	R^2	χ^2	$q_{e,\,cal}$
0.5	28.9	0.011	0.00015	0.9942	0.82	0.551	27.5	3.17	2.21	0.9673	0.77	30.3
1.0	40.5					0.393	40.6					38.2
2.0	47.9					0.245	53.6					48.9
3.0	59.1					0.184	58.6					55.2
4.0	62.3					0.141	62.3					61.6
5.0	62.4					0.116	64.4					66.5
							$q_m = 73.3$					

Table 2 Langmuir and Freundlich isotherm constants of cutting fluid sorption onto MSB

Concentration (% w/v)	$q_{e,\,exp}$	Langmuir Isotherm						Freundlich Isotherm				
		$a_{m,\,L}$	K_L	R^2	χ^2	R_L	$q_{e,\,cal}$	n	K_F	R^2	χ^2	$q_{e,\,cal}$
0.5	108.8	0.85	0.0016	0.9981	113.36	0.103	2.1	5.59	86.94	0.9716	14.60	102.4
1.0	199.9					0.057	179.3					243.7
2.0	370.0					0.030	404.2					338.4
3.0	450.6					0.021	487.1					423.4
4.0	494.7					0.015	510.7					490.8
5.0	519.7					0.012	517.7					531.6
							$q_m = 530.8$					

fluid adsorption onto sugarcane bagasse and modified sugarcane bagasse as presented in Table 1 and Table 2, respectively. Maximum adsorption capacity following Langmuir isotherm represented by Eq. (18)

$$q_m = \frac{a_{m,L}}{K_L} \tag{18}$$

where q_m is maximum monolayer adsorption capacity (mg/g)

The maximum monolayer adsorption capacity of cutting fluid onto sugarcane bagasse and modified sugarcane bagasse were 73.3 and 530.8 mg/g, which is presented in Table 1 and Table 2, respectively. It shows that the modified sugarcane bagasse has maximum monolayer adsorption capacity which is greater than sugarcane bagasse.

The essential characteristic of the Langmuir isotherm parameters can be used to predict the affinity between the adsorbent and adsorbate using separation factor or dimensionless equilibrium parameter (R_L) [19], as expressed in the following Eq. (19).

$$R_L = \frac{1}{1 + K_L C_0} \tag{19}$$

where R_L is separation factor (Dimensionless)

The value of separation factor provides important information about the nature of adsorption. The value of separation factor indicated the type of Langmuir isotherm to be irreversible ($R_L = 0$), favorable ($0 < R_L < 1$), linear ($R_L = 1$) and unfavorable ($R_L > 1$). It was found that at initial cutting fluid concentration in the range 0.5–5.0 % w/v, the separation factor of adsorption for sugarcane bagasse and modified sugarcane bagasse with cutting fluid was 0.551–0.116 and 0.103–0.012, respectively. They are in the range of 0–1 which confirms the favorable adsorption.

Freundlich isotherm is the earliest known relationship describing the sorption equation. Freundlich equation is the empirical relationship whereby it is assumed that the sorption energy of a protein binding to a site on an adsorbent depends on whether or not the adjacent sites are already occupied. One limitation of the Freundlich isotherm is that the amount of adsorbed solute increases indefinitely with the concentration of solute in the solution [20]. This fairly satisfactory empirical isotherm can be used for non-ideal sorption that involved heterogeneous sorption and is expressed by the following Eq. (20).

$$q_e = K_F \, Ce^{1/n} \tag{20}$$

These equation are linearized by taking the logarithm both sides, as represented by Eq. (21)

$$\log q_e = \log K_F + 1/n \log C_e \tag{21}$$

where K_F is Freundlich isotherm constant (mg/g) $(L/mg)^{1/n}$ and 1/n is heterogeneity factor (Dimensionless)

K_F and 1/n can be determined from the intercept and slope of the linear plot of log q_e versus log C_e. The valves of R^2 are shown in Figure 5. The calculation of K_F and n for cutting fluid adsorption onto sugarcane bagasse and modified sugarcane bagasse is presented in Table 1 and Table 2, respectively.

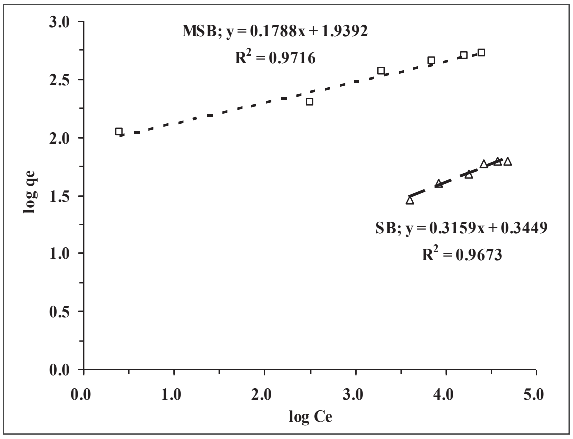

Figure 5 Freundlich isotherm of cutting fluid adsorbed onto: Δ SB and □ MSB.

From comparing the R^2 of both isotherms, the Langmuir isotherm showed R^2 higher than Freundlich isotherm. This showed that Langmuir isotherm is consistent with the results obtained from the experiment which can cause errors. The use of R^2 is limited to solving linear forms of isotherm equation. It will give a better fit correlation to the higher C_e value date points. This is an obvious inherent bias in the linearised isotherm plots [21]. Due to the inherent bias resulting from linearisation, chi-square (χ^2) error function was employed in this study to evaluate the isotherm constants and to select the best fit isotherm. Chi-square can be calculated as in Eq. (22).

$$\chi^2 = \sum \left(\frac{(q_{e,exp} - q_{e,cal})^2}{q_{e,exp}} \right) \tag{22}$$

where, $q_{e,\,cal}$ is theoretical adsorption capacity (mg/g) and $q_{e,\,exp}$ is experimentally adsorption capacity (mg/g)

The value of chi-square, error measurement was, presented in Table 1 and Table 2 for adsorption of cutting fluid onto sugarcane bagasse and modified sugarcane bagasse, respectively. It showed that the value of the Freundlich isotherm is lower than

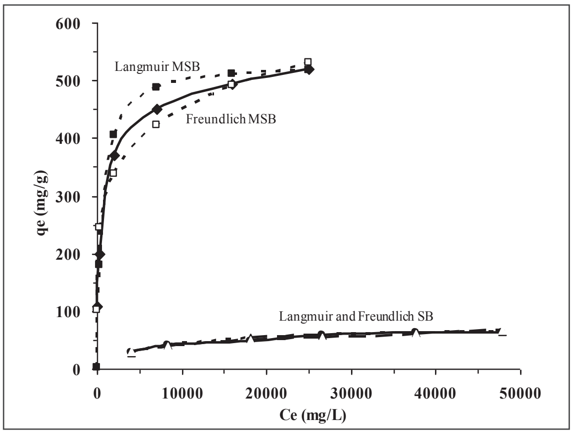

Figure 6 Experiment equilibrium adsorption of cutting fluid onto: ● SB and ♦ MSB.

Langmuir isotherm for cutting fluid adsorption onto sugarcane bagasse and modified sugarcane bagasse. The data were obtained from theoretical Langmuir and Freundlich isotherms together with the experimental points as presented in Figure 6. It was found that, the Freundlich isotherm fitted the experimental data than the Langmuir isotherm. Thus suggested that Freundlich isotherm closely fitted the experimental results. The heterogenity in the surface or pore of sugarcane bagasse and modified sugarcane bagasse will play a role in cutting fluid adsorption [22].

3.5 Batch Design

Adsorption isotherm relations are used to predict the design of single-stage batch adsorption systems. A schematic design is shown in Figure 7. The solution to be treated contains V solvent (L), and the initial concentration is reduced from C_0 to C_1 (mg/L). The amount of adsorbent is M and the solute concentration increases from q_0 to q_1 (mg/g). If fresh adsorbent is used, $q_0 = 0$, as it proceeds, the mass balance equates the solute removed from liquid that is picked up by the adsorbent. The mass balance equation for the sorption system can be written as Eq. (23) [23].

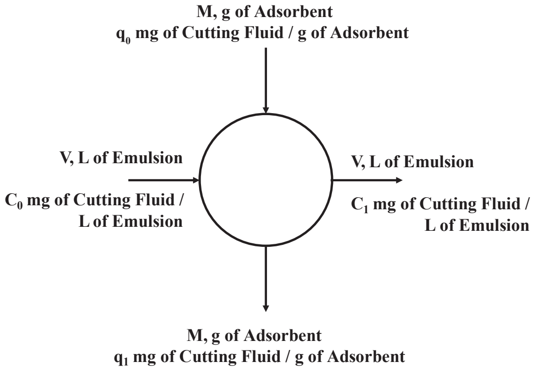

Figure 7 Single stage batch adsorption.

$$V(C_0 - C_1) = M(q_0 - q_1) = Mq_1 \tag{23}$$

Under equilibrium condition, equation is as follows Eq. (24).

$$C_1 \rightarrow C_e \text{ and } q_1 \rightarrow q_e \tag{24}$$

For the sorption isotherm, this study confirmed that the equilibrium data from cutting fluid adsorption onto sugarcane bagasse and modified sugarcane bagasse best fitted in Freundlich isotherm, that is why the Freundlich data was applied in Eq. (23) and substituting q_e from Eq. (20) and rearranging which gave the following Eq. (25).

$$\frac{M}{V} = \frac{\left(C_0 - C_e\right)}{q_1} = \frac{\left(C_0 - C_e\right)}{q_e} = \frac{(C_0 - C_e)}{K_F C_e^{1/n}} \tag{25}$$

Equation (25) permits analytical calculation of the adsorbent emulsion ratio for a given change in emulsion concentration, C_0 (5,000 mg/L) to C_e (2.5 mg/L). Figure 8 shows a series of plots (100 % cutting fluid removal at different emulsion volume 1–10 L) derived

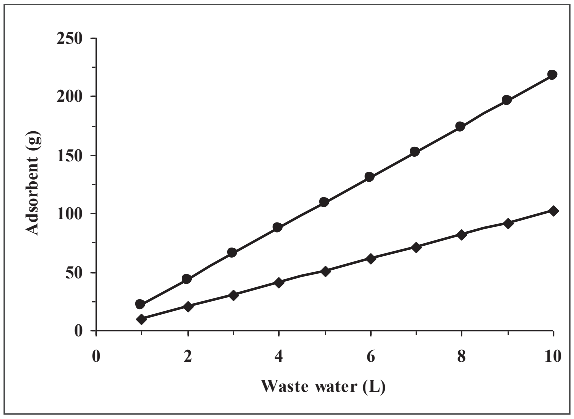

Figure 8 Adsorbent mass vs. volume for removal 100% of cutting fluid: ● SB and ♦ MSB.

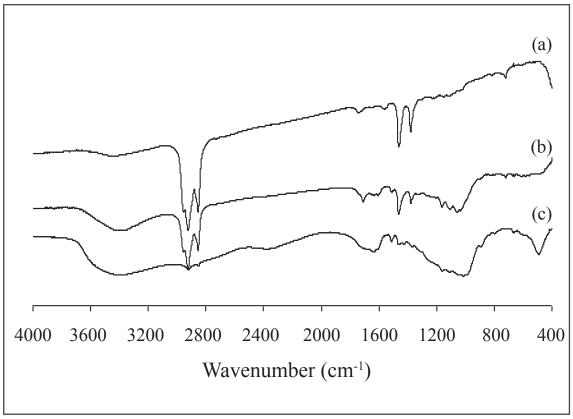

Figure 9 FT-IR spectra: (a) Cutting fluid, (b) MSB after adsorption and (c) MSB before adsorption.

from Eq. (25) for the adsorption of cutting fluid onto sugarcane bagasse and modified sugarcane bagasse. The amount of adsorbents required for cutting fluid removal 1 L was 21.7 g and 10.2 g for sugarcane bagasse and modified sugarcane bagasse, respectively.

3.6 FT-IR Spectra

Figure 9 (a) shows FT-IR spectra of cutting fluid. The alkane appeared at 2,925 and 2,855 cm^{-1}, methylene and methyl appeared at 1,465 and 1,375 cm^{-1}. The long chain of methylene group, which has more than four carbon atoms, appeared at 720 cm^{-1} [24]. Figure 9 (b) shows the spectra of modified sugarcane bagasse after adsorption of cutting fluid. It was found that alkane appears at 2,927 and 2,869 cm^{-1}, methylene at 1,468 cm^{-1} and methyl at 1,379 cm^{-1}. The appearance of alkane, methylene and methyl groups onto modified sugarcane bagasse after adsorption of cutting fluid demonstrated that the adsorption of cutting fluid occurred onto modified sugarcane bagasse. Figure 9 (c) shows spectra of modified sugarcane bagasse before the adsorption of cutting fluid.

4. Conclusion

The point of zero charge of sugarcane bagasse and modified sugarcane bagasse was pH 5.2 and 2.2, respectively. The percent adsorption and adsorption capacity increased with increasing amount of adsorbent and initial concentration of cutting fluid due to increasing surface area of adsorbent and driving force, respectively. The adsorption capacity of sugarcane bagasse and modified sugarcane bagasse on 5.0 g for cutting fluid concentration 5.0 %w/v was 62.4 and 519.7 mg/g, respectively. Equilibrium adsorption was fitted by Freundlich isotherm. The FT-IR proved the cutting fluid adsorption onto modified sugarcane bagasse.

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