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38**crystal violet dye by adsorption using bentonite – alginate composite** MARK **Rizka** Fabryantya **,1, Chrissila** Valenciaa **,1, Felycia Edi**

Soetaredjoa,, Jindrayani Nyoo Putrob, Shella Permatasari Santosoa, Alfin Kurniawanb,

14**Yi-Hsu Jub, Suryadi Ismadjia, a Department of Chemical Engineering, Widya Mandala Surabaya Catholic University, Kalijudan 37, Surabaya 60114, Indonesia b Department of Chemical Engineering, National Taiwan University of Science and Technology,**

Taipei, Taiwan ARTICLE INFO ABSTRACT Keywords: The microwave rapid heating

30**method was successfully applied** to **the** production **of**

bentonite – alginate com- Alginate posite which is effectively used as a sorbent for dye removal. The irradiation method has been proven to assist Bentonite Composite effectively in the formation of sorbent pores that facilitate the permeation of dye solution. Three nanocomposite Adsorption models were prepared by varied the mass of bentonite to a certain mass of sodium alginate.

37**In this study, the** Crystal violet **adsorption** performance **of** bentonite – **alginate** nanocomposites **were**

tested for the removal of crystal violet dye. The characterizations of the composites were conducted

39**using Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), and** nitrogen sorption methods The adsorption experiments were carried out in batch mode at three different temperatures (30, 50, and 70 °C). The adsorption equilibria data were fitted by Langmuir and Freundlich isotherms. The nonlinear fitting coefficient R2 indicates

34**that the adsorption follows** both **the isotherm**

models well. The best adsorption capacity is showed by the composite prepared with the highest proportion of bentonite mass. The high-temperature promotes the ad- sorption capacity of the composite, where at 70 °C the adsorption capacity is reached 601.9339 mg/g (Langmuir parameter, qmax) or 36.3399 (mg/g)(L/mg) −n (Freundlich parameter, KF). The adsorption kinetic results follow the pseudo-second-order model better than the pseudo-first-order which indicated by higher R2 values (0.9209 to 0.9916). As indicated by the thermodynamic properties, the adsorption process is controlled by chemisorp- tion. 1. Introduction Some industrials such as textiles, ceramics, papers, and printing are known as the industries that use significant amounts of dye to color their products [1–4]. During the coloring process, some amount of dyes are absorbed in the product, and some of them will end up in the wastewater. Currently, thousands of synthetic dyes are available in the market. Some of them are safe to human and can be used to color food and beverage, but some of them are harmful or even dangerous to human health. Among these dyes, crystal violet is one kind of dyes which possess adverse effects to human health. It may cause eye burn leading to permanent cornea/eye damage. Its inhalation gives rise to a short period of rapid or difficult breathing, nausea, vomiting, profuse sweating, hypermotility, diarrhea, and abdominal pain [1]. Depending on its application, some of the synthetic dyes are de- signed to be chemically or biologically resistant, and the presence of these kinds of dyes in the environment can cause severe environmental problems. The persistent of this type of dyes in the environment

31**due to** its **complex chemical structure, they are resistant to** breakdown **by chemical, physical and biological treatments** [5]. **The** existence of **dye**

(such as crystal violet) in a water body, even in just 1 ppm in con- centration, is highly visible and often disturbs the photosynthesis pro- cess of water plants due to the blockage of the penetration of sunlight in the water [6]. Crystal violet dye at the level of 1 ppb is said to be toxic and possibly mutagenic to human and animals [7]. Therefore, proper treatments are required to remove these pollutants from wastewater before discharging into the environment. There are many methods available to treat wastewater containing dyes such as physical treatment including adsorption, membrane filtration, ion- exchange and electrochemical techniques [8–11]; physicochemical treat- ment including coagulation and flocculation, reverse osmosis, chemical oxidation, ozonation [11–14]; biological treatment including activated sludge, bacterial action [15,16]. Among those methods, adsorption is more promising than the other methods due to its economic, flexibility, and ⎕ Corresponding authors.

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efficiency of the process. The effectiveness of the adsorption process for dyes removal strongly depends on the adsorbent used. Several commer- cially available adsorbents have high adsorption capability such as acti- vated carbon. However, the main obstacles to using activated carbon as the adsorbent for wastewater treatment is its price. An emerging dye re- moval method, the photocatalytic degradation, promises an en- vironmentally friendly and sustainable process. In this process, the pre- sence of a catalyst is required to convert light into energy; the generated energy will then initiate the formation of reactive species which are re- sponsible for degrading the dyes. The catalyst used is prepared by using photo-anode metal oxide material, such as TiO2, ZnO, SnO2, and ZrO2. Even though the light is an inexpensive energy source, however, the process itself is impractical and required expensive equipment, only ef- fective for the small amount of dyes, and have the possibility to generate harmful reactive oxidating species (ROS) [17–19]. Some magnetic metal oxide powders (such as Fe2O3, Fe3O4, and Al2O3) are known as potential adsorbents. The removal method by using metal oxide depends on the sequestering ability of the dye to form complexes with metal [20–24]. However, similar to photocatalytic process, the magnetic metal oxides may initiate the formation of ROS. Therefore, the efficient adsorption process by using in-expensive adsorbent which is not generating ROS still becomes a trending topic. In this study, a new adsorbent was synthesized from clay mineral and natural polymer, namely bentonite and alginate. A fast and easy method involving microwave irradiation was employed for bentonite – alginate composite preparation. This microwave irradiation method is efficient in heating the molecules of the materials (bentonite and algi- nate) by introducing high radiation energy. The heated molecules are rapidly moved and collided each other as the result of the high-energy inducement; this phenomenon will help the molecules to incorporate each other. The adsorption capability of the composites was tested to remove crystal violet dye (cationic dye) from aqueous solution. 2. Materials and methods 2.1. Materials Crystal violet dye (CI = 42555, dye content ≥90%, molecular for- mula C25H30ClN3, MW 407.99 and λmax = 590 nm) was obtained from Merck (Merck Co., Germany). Bentonite was supplied from Pacitan, East Java, Indonesia. Sodium alginate was purchased from CV. Nura Jaya, Surabaya, Indonesia. Hydrochloric acid (HCl), sodium hydroxide (NaOH), calcium chloride (CaCl2)

2**were purchased as** an **analytical grade from Merck** (Merck Co., **Germany).** All chemicals were **used without any further purification.**

2.2. Acid activation of bentonite The initial moisture content of the bentonite utilized in this study was around 30% (was obtained directly from the bentonite mining lo- cated in Pacitan, East Java, Indonesia). Reproducibility of the experi- ments was maintained by uniforming the initial moisture content of the raw bentonite to 10%. Subsequently, for pretreatment, the dried ben- tonite was pulverized until its particle size −100/+120 mesh. The bentonite was pretreated using a modified acid activation method [25]. Bentonite was activated by immersing into the 5 N of HCl (1:10 w/v ratio) solution. During the activation process, the mixture was kept under a constant mechanical stirring at 200 rpm. The temperature of the activation process was maintained at 60 °C for 2 h. The resulting acid – activated bentonite was filtered and rinsed with deionized water

6**and dried in an oven (Memmert UM 400) at 105 °C.** To homogenize **the** particle size of **purified bentonite,** bentonite **was crushed**

and screened to obtained smaller particle size −180/+200 mesh. Finally, the acid- activated bentonite was kept in a desiccator until further use. The choice of the parameters (time of activation, temperature, type of acid, and the ratio of acid) for bentonite activation was based on our preliminary experiments. In our preliminary experiments we chose several variables of the process (time of activation: 1,2, and 3 h; tem- perature: 40, 50, and 60 °C; type of acid: H2SO4 and HCl; and the ratio of acid w/v: 1:1, 1:10, 1:15). The adsorption capacities of acid activated bentonites which prepared under different variation parameters were tested for the adsorption of crystal violate dye, and the parameters that produce acid activated bentonite with the highest adsorption capacity was chosen for subsequent experiments. 2.3. Preparation of bentonite-alginate composite

8**A 2% (w/v)** of **sodium alginate solution was prepared by mixing 2 g of sodium alginate** with **100 mL** of **deionized water,**

and then bentonite clay was added to the solution. The ratio of bentonite clay/sodium alginate were 2:5; 3:5; 4:5 w/w. As for the simplification purpose, the composites were designated as 2B:5A, 3B:5A, and 4B:5A for the mass ratio of bento- nite (B) to sodium alginate (A) of 2:5; 3:5; 4:5 w/w respectively. The mixture was stirred under constant stirring at 500 rpm for 3 h at 50 °C. Subsequently, the mixture was irradiated in a microwave oven at 700 W for 90 s. After the formation of composite completed, the homo- geneous mixture was dropped (using pipette) to 1%

35**(w/v) calcium chloride solution to form** gel spheres. **The**

excess of calcium chloride so- lution was separated from the beads by washing

6**with deionized water at least three times and dried in an oven (Memmert UM 400)** at 50 °C **for** 24 **h. The** resulting dried **bentonite-** alginate nanocomposite **was**

stored in a clean container and kept in a desiccator until further use.

2**2.4. Characterization The characterization of** acid – activated **bentonite and bentonite** – alginate composites **was conducted using**

Fourier Transform Infrared spectroscopy (FTIR), X-Ray diffraction (XRD), scanning electron mi- croscopy (SEM), and nitrogen sorption methods. FTIR analysis of the bentonite, alginate, bentonite-alginate nanocomposite was carried out using a Shimadzu/FTIR-8400S spectrometer with KBr pellets from 400 to 4000 cm−1. The surface morphologies of acid-activated bentonite and bentonite – alginate nanocomposites were obtained using

32**Scanning Electron Microscopy.** The surface **analysis was carried out** on **a**

JEOL JSM-6500F field emission SEM at 15 kV. Before

2**SEM analysis, the samples were coated with** a **thin layer** of **platinum** (3 nm). **The** coating process **was**

conducted for 90 s in argon atmosphere using a fine auto coater (JFC-1600, JEOL, Ltd., Japan). XRD analysis of bentonite and composites was carried out using

2**a Philips X'pert** Xray **Diffractometer. The XRD patterns were** obtained **at** 40 kV **and**

30 mA and monochromatic high-intensity Cu Kα1 (λ = 0.15405 nm) was used as the source of radiation. The nitrogen sorption isotherms of the samples were obtained at a temperature of −176 °C and relative pressure (p/po) of 0.001 to 0.999 using Micromeritics ASAP 2010 sorption analyzer. Before the nitrogen sorp- tion measurement, all

15**samples were degassed at 150 °C** in a **vacuum condition for 24 h. The**

standard Brunauer–Emmett–Teller (BET) equation was applied for the determination of the BET surface area [26,27].

9**Total pore volume was calculated at a pressure**

where

9**all pores were filled with nitrogen gas,**

approximately at a p/po 0.999. The pH-drift procedure was used to determine the

29**point of zero charges (pHPzc) of adsorbents**

[28]. A stock solution of 0.01 N NaCl was prepared. The solution was then poured into a series of conical flasks (50 mL each), the pH of each flask was varied from 2 to 10. Adjustment of pH was done by using 0.1 N NaOH or HCl solutions. 0.2 g of ad- sorbent was then

13**added to each flask and shaken** at room temperature **for 48 h. The** initial and **final pH** of the solution **was measured** by **using** a digital **pH-meter (Schott CG-825). The pHPzc is** determined as **the** pH **where the curve** of **pHfinal** vs **pHinitial crosses the line** when **pHfinal**

= pHinitial. 2.5. Adsorption experiment The adsorption kinetic study of crystal violet onto bentonite, sodium alginate and bentonite-sodium alginate composites was conducted at 30 °C. A liter of crystal violet dye stock solution with an initial con- centration

29**of 300 mg/L was** prepared and poured **into a series of Erlenmeyer flasks,**

each containing 50 mL solution. The specific amount of adsorbent (0.5 g) was added to each flask. The flasks were

15**shaken at 100 rpm in** a **Memmert**

water bath for certain period of times. After certain time reached, the remaining crystal violet dye solution was measured by using a spectrophotometer. The

7**adsorption isotherm study was conducted in** a **batch** process **at three different temperatures** (30, 50, **and**

70 °C). The adsorption

9**isotherm study was** carried out **by adding** various amounts **of adsorbent (0.1–** 1 g) **into** a series of **Erlenmeyer flasks, each** containing 50 mL **of**

crystal violet dye

6**solution with an initial concentration of 300 mg/L. The** flasks **were shaken**

at 100 rpm until the

2**equilibrium condition was reached,** then **the** solid **was separated from the** solution **by centrifugation at** 5000 rpm **for**

10 min. During all adsorption processes, the temperature of the system was con- trolled at desired temperature using thermal controller embedded in shaking water bath. The initial and equilibrium concentrations of the crystal violet in the solution were determined using a Shimadzu UV mini-1240 spectrophotometer.

40**The amount of** crystal violet **adsorbed** by **the adsorbent at equilibrium** condition **(Qe, mg/g) was** determined **by the following**

equation: Qe = Ci − Ce m V

19**(1) Where** Ci **and Ce are the initial and equilibrium concentrations (mg/L),** re- spectively, **V is the volume of solution (L), and m is the mass of** adsorbent (g). **A**

calibration curve with a series of crystal violet concentration (0–100 mg/L) was prepared prior for the determination of initial and final dye concentra- tion. The spectrum measurements were done with a wavelength of 590 nm. Each set of the experiments was done in triplicate, the uncertainty in the measurement results was shown by the standard deviations which re- presented as error bars. 3. Result and discussion The formation mechanism of bentonite–alginate composite is shown in Fig. 1. The

35**composite was prepared by** mixing **the sodium alginate** and bentonite **in**

water. Subsequently, the mixture was irradiated by using the microwave. The composite was then cured by dropping in the 1% (w/w) CaCl2. Silanol group of bentonite is readily protonated when immersing in the water; this causes a positive charge of the silanol group. Likewise, the Na+ ion of sodium alginate is readily ionized when dissolving in the water, leading to a negative charge of the carboxyl group. The high energy of microwave will heat up the molecules of both materials and initiate the interaction between the positive charge Fig. 2. Fourier Transform Infrared (FTIR) Spectra of adsorbents at range of 4000–400 cm−1. silanol and negative charge carboxyl groups. The curing effect of the composite was then initiated by the Ca+ ions of CaCl2. 3.1. Characterization The surface functional groups of bentonite-alginate nanocomposites were obtained by Fourier Transform Infrared (FTIR) spectroscopy analysis. FTIR analysis was conducted to confirm the formation of the composited by comparing the alteration of a functional group on the surface of the composites, alginate, and bentonite. The alterations of the functional group before and after the adsorption of crystal violet were also observed. Fig. 2 shows the FTIR spectra of acid – activated bentonite, sodium algi- nate, and bentonite – alginate composites. Several surface functional Fig. 1. The formation mechanism of bentonite–alginate composite. The composite was prepared at 3 different mass ratio of bentonite to alginate of 2:5, 3:5 and 4:5 w/w. Table 1 FT-IR Assignments of Bentonite, Alginate and

Composites. IR Assignments Wavenumber (1/cm) Literature Bentonite (B) Alginate (A) 2B:5A 3B:5A 4B:5A (Si,Al)-OH stretching -OH stretching COO− stretching CH2 bending vibration R–O–R stretching –OH vibration 3629 – 3129 3148 1636 1604 – 1412 1020 1030 509 – 464 – 3608 3620 3247 3213 1621 1686 1421 1419 1091 1082 538 526 478 471 3639 3236 1624 1423 1047 511 465 3600–3700 3200–3600 1500–1800 1400–1500 1050–1100 400–600 groups found in acid – activated bentonite are as follow:

4**hydroxyl stretching of (Si,** Al **)-OH** (3629 **cm−1), hydroxyl stretching of** HeOeH (3192 **cm−1), hydroxyl bending of H2O**

deformation vibration due to ad- sorbed water (1636 cm−1), SieOeSi stretching (1020 cm−1), AleOH (916 and 643 cm−1), SieO bending vibrations (509 cm−1) [29]. The broadband around 3148

24**cm−1 in the** FTIR **spectrum of** sodium **alginate** (Fig. 2) **is**

correlated with OeH stretching, while

4**the peaks appearing at** 1604 **and** 1412 **cm−1** are associated with **asymmetric and symmetric stretching vibrations of free carboxyl groups, respectively. The peak observed at** 1030 **cm−1 was attributed to the stretching of**

CeOeC. The characteristic peaks for both of bentonite and sodium alginate are found in all composites as summarized in Table 1. Al- teration some characteristic peaks of both raw materials are observed in composites such as (Si, Al)eOH group (3608–3639 cm−1), eOH vi- bration of bentonite (465–538 cm−1). The peaks for COO− stretching, CH2 bending vibration and R–O–R stretching for the composites were shifted from the original peaks shown for alginate and bentonite. The COO− stretching for alginate observed at 1604 cm−1 and in bentonite at 1636 cm−1, shifted to 1621–1686 cm−1 for composites. The CH2 bending for alginate is ob- served at 1412 cm−1, shifted to 1419–1423 cm−1 for composite. The R–O–R stretching for alginate is 1030 cm−1 and for bentonite is 1020 cm−1, shifted to 1047–1091 cm−1 for all composites. The shift in the peak for COO− is indicated the electrostatic interaction between the negative charge carboxyl group of sodium alginate and the positive charge on the surface of bentonite [30–32].

4**Thus, the FTIR spectra of** sodium **alginate-** bentonite composite **confirmed the interaction** be- tween **alginate and** bentonite. **The**

X-Ray Diffraction (XRD) patterns for sodium alginate, acid – activated bentonite, and composites are given in Fig. 3. XRD analysis was conducted to observe the change in the degree of crystallinity caused by the merging between alginate and bentonite. Sodium alginate has an amorphous structure as seen in the XRD pattern (Fig. 3). Some characteristic peaks of montmorillonite were observed in XRD pattern of acid – activated bentonite (2θ = 6.44, 20.18, 30.06, 35.28, and 60.25°). The basal spacing of acid – activated bentonite at 2θ = 6.44 corresponds to d001 = 1.37 nm. After encapsulation with sodium algi- nate to form the composites, the value of d001 for all composites almost similar to the basal spacing of acid – activated bentonite. This phe- nomenon indicates that the alginate molecules did not intercalate to silicate layers of montmorillonite, the bonding between alginate and montmorillonite only through the electrostatic interaction between positively charged of montmorillonite with the carboxyl group of so- dium alginate. This XRD result confirms the result of FTIR analysis. The micrographs of acid-activated montmorillonite obtained by using scanning electron microscope (SEM), 4B:5A composite, 3B:5A composite, and 2B:5A composite are depicted in Fig. 4. SEM observa- tion was conducted to compare the difference in surface morphology between alginate, bentonite, and composites. Obviously, the surface morphology of composites is different with

32**acid – activated bentonite. The** surface **of acid – activated bentonite**

quite smooth and rigid, while the composites 3B:5A and 2B:5A display some porous structure. This porous surface is possibly facilitating the permeation of water into the structure of composites. Fig. 5 depicts the nitrogen sorption isotherms of acid – activated bentonite and composites. Acid – activated bentonite has a combination between type I and type II isotherm with broad hysteresis loop.

2**At low relative pressure** (p/po) **the** isotherm **is type**

I

2**indicated by rapid intake of** nitrogen **gas**

by the bentonite. As the pressure increases, the isotherm gradually increase until a certain relative pressure rapid increase of the intake of nitrogen gas is observed (type II). The broad hysteresis loop is considered as type H2 hysteresis. This hysteresis indicates that activa- tion of natural bentonite with 5N HCl solution created some complex network of interconnected pores or interlayers with bottleneck and contractions

16**[33]. The BET surface area of** the samples was **calculated** at **a**

7**relative pressure** between **0.05 to 0.3, while pore volume was** de- termined **at** the highest **relative pressure.**

The BET surface area and pore volume of acid − activated bentonite are 73.5 m2/g and 0.112 cm3/g respectively. The nitrogen sorption of the composites is also given

8**in Fig.** 5. **The BET surface area and pore volume** of 4B:5A composites are 56.8 m2/g and 0.085 cm3/g; while for composite 3B:5A are 33.5 m2/g and 0.052 cm3/g, and for composite 2B:5A are 21.6 m2/g and 0.031 cm3/g. The decrease of BET surface area and pore volume of the composites mainly due to less bentonite structure in the composite. The nitrogen sorption of composites are a combination type I, II, and IV with H3-H4 hysteresis loop. 3.2. Effect of pH To study the surface charge behavior (anion or cation exchange- ability) of all adsorbents (acid-activated bentonite, sodium alginate, Fig. 3. X-Ray Diffraction (XRD) analysis of sodium alginate, acid activated bentonite, and composites. and bentonite-alginate composite) in the solution, pHPzc (point of zero charges) of all adsorbents were analyzed using the pH-drift procedure. Fig. 5. Nitrogen sorption isotherm of acid-activated bentonite and composites. alginate was 7.07, and for bentonite-alginate composites was 5 to 6. The difference between the pHPzc values is due to the difference in acidity of each adsorbent. A low pHPzc indicates that the compound is acidic and easily protonated. The pHPzc value is obtained when the adsorbents have a neutral charge. At acidic pH where pH < pHPzc, the occurrence of excessive H+ ions cause imbalance positive charge and leading to protonation of the adsorbents. Meanwhile at high alkaline pH where pH > pHPzc, the excess OH− ions (originated from the ad- dition of base) are cause the deprotonation of the H+. The deproto- nation will lead to a negative charge of the adsorbents. The forms of protonated, neutral, and deprotonated species of each adsorbent were depicted in Supplementary data Figs. S1–S3. The influence of pH on the adsorption of crystal violet onto ad- sorbents was studied at pH range of 3–9. The

10**pH of the solution** gave significant **impact on the surface** charges **of the**

adsorbents; it is asso- ciated with the

10**protonation and deprotonation of silanol groups** at **the active sites** of bentonite **and**

interaction with the negative carboxylate groups on alginate. The maximum uptake of crystal violet by bentonite, alginate, and composites were achieved at pH 4.1, 8.9, and 8.0, re- spectively. The removal percentage obtained at these pHs are 72.2%, 81.5%, 87.6%, 93.5%, and 97.8% for bentonite, alginate, composite 2B:5A, 3B:5A, and 4B:5A, respectively. The main reason for this out- come is that at pH above pHPzc, the adsorbent will tend to deprotonate. This will provide a negative charge on the surface of the adsorbent. The adsorption mechanism of crystal violet dye by composite at pH = pHPzc and pH > pHPzc is depicted in Supplementary data Fig. S4. The com- posite can adsorb more of crystal violet dye at pH > pHPzc because it has higher negative charge. Since crystal violet is a cationic dye, the interaction with a negative charge of a surface enhances the amount of dye adsorbed by the adsorbent due to the electrostatic interaction. Fig. 4. SEM images of (a) bentonite, (b) 4B:5A composite, (c) 3B:5A composite, and (d) 2B:5A composite at same magnification of 15,000× and accelerating voltage of 15 kV. The composites have a

41**positive charge at pH** less than **pHpzc, while at pH** higher than **pHpzc the** composites possess **a negative charge. The** uptake **of** the crystal violet dye by the composites was strongly influ- enced by pH of the adsorption process. The pHPzc values for acid – activated bentonite was 3.88, for sodium

37**3.3. Adsorption kinetic study The** kinetic **adsorption of**

crystal violet dye onto composites was studied at 30 °C with an initial concentration of 300 ppm. The well-known

17**kinetic models: pseudo-first order and pseudo second order** equations **were used to** correlate the **kinetic** experiment **data. The pseudo first order** that **also known as** the **Lagergren**

first-order rate expression based on the adsorbent capacity and is generally expressed as [34]: Fig. 6. Adsorption kinetic data of

24**crystal violet onto acid – activated bentonite** and **alginate,**

and theoretical kinetic models of: (a) Pseudo-First Order, (b) Pseudo-Second Order,

3**at initial crystal violet concentration of** 300 **mg/L,**

temperature 30 °C. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.) Fig. 7. Adsorption kinetic data of crystal violet onto composites and theoretical kinetic models of: (a) Pseudo-First Order, (b) Pseudo-Second Order Model,

3**at initial crystal violet concentration of** 300 **mg/L,**

temperature 30 °C. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.) qt = qe(1 − exp(−k1t)) (2) The

12**pseudo-second order assumes that chemisorption is dominant and controls the adsorption as rate-limiting step**

and it has the form: qt = qe⎜ ⎛⎝1 +qekq2etk2t⎠ ⎟⎞ (3) where k1 (min−1) and k2 (g mg−1 min−1) are time scaling factor that indicates how much time needed to reach the equilibrium in the ad- sorption system, 36**qt and qe are the** amounts **of** crystal violet **adsorbed (mg/g) at time t and** the **equilibrium** condition, **respectively. The**

adsorption kinetic study is necessary to provide the adsorption process

9**mechanism based on its rate controlling steps that** consolidate chemical reaction **and**

mass transport. The experimental of the ad- sorption kinetic data and the theoretical calculation using pseudo-first and pseudo-second models are given in Figs. 6 and 7. In these figures, the experimental

33**data are represented by** the **symbols while** theoretical values of **pseudo-first** order **and** pseudo **-second order are** given in **solid lines. The parameters**

of both of these equations are summarized in Table 2. As shown in Table 2, sodium alginate possesses larger

11**rate constant (k) of both kinetic**

models; this means that sodium alginate has smaller particle size thus the equilibrium condition is reached faster than other adsorbents. However, the parameter qe indicates that at equilibrium condition,

12**the amount of crystal violet adsorbed**

by sodium Table 2 Pseudo-First-Order and Second-Order Parameters of Kinetic Adsorption between Crystal Violet

17**at initial concentration of** 300 **mg/L with**

Bentonite, Alginate and Composites. Adsorbents

23**Pseudo First Order Pseudo Second Order k1 (min−1) qe (mg/g) R2 k2 (g/mg min−1) qe (mg/g) R2** Bentonite (B) Alginate **(A)**

2B:5A 3B:5A 4B:5A 0.0161 82.7693 0.0474 64.6494 0.0203 135.9726 0.0202 138.8209 0.0217 147.6164 0.8257 0.0004 0.9784 0.0010 0.9835 0.0002 0.9606 0.0002 0.9875 0.0002 83.6173 71.6565 153.3419

156.2010 169.2418 0.9209 0.9819 0.9916 0.9883 0.9901 Fig. 8. Experimental Adsorption Data for Crystal Violet dye onto Composite 2B:5A and the fits of the (a) Langmuir, (b) Freundlich,

3**at initial crystal violet concentration of** 300 **mg/L,**

temperature 30, 50, and 70 °C. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.) Fig. 9. Experimental Adsorption Data for Crystal Violet onto Composite 3B:5A and the fits of the (a) Langmuir, (b) Freundlich,

3**at initial crystal violet concentration of** 300 **mg/L,**

temperature 30, 50, and 70 °C. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.) alginate is smaller than the other adsorbents. At equilibrium condition, the crystal violet dye is adsorbed at the most by composite 4B:5A and then followed by 3B:5A, 2B:5A, bentonite, and alginate. The results indicate that the combination of bentonite-alginate gives a synergistic effect in the adsorption of crystal violet dye. The pseudo-second order model correlates the kinetic data better (R2 > 0.9883) than pseudo- first order. 3.4. Adsorption isotherm study The adsorption

24**of crystal violet onto acid-activated bentonite,**

al- ginate, and composites were studied at

5**temperatures of 30 °C, 50 °C, and 70 °C** with **the initial** concentration **of**

crystal violet of 300 mg L−1. The experimental adsorption data were correlated with Langmuir and Freundlich adsorption equations. The Langmuir model can be expressed mathematically as follows: qe = qm 1 +KLKCLeCe (4) where qm is the

10**maximum adsorption capacity** of **the adsorbent,** and it **corresponds to the monolayer surface coverage** (mg **/g),** KL is **Langmuir constant** represents the **adsorption affinity (L/** mg). **The**

Freundlich equation is also one of the most popular two-para- meters isotherm model. This equation describes the adsorption behavior in heterogeneous systems. The mathematical expression of Freundlich model is given as follows: qe = KF Ce1/n (5) here, KF is the Freundlich parameter associated with

16**the adsorption** affinity **((mg/g)•(** mg **/L)–n) and n is** a **parameter** that characterizes **the** system heterogeneity [35]. The plots of experimental adsorption data with Langmuir and Freundlich equations are given in Figs. 8–12. The parameters of Lang- muir and Freundlich

7**equations obtained from the** fitting **of the** ex- perimental results **are summarized in Table 3.**

From Figs. 8–12 it can be seen that temperature has a positive influence on the amount of crystal violet adsorbed by the adsorbents. When the temperature increases, the

21**adsorption capacity of** adsorbents **increased. With the** increase **of** temperature, **the**

interaction between the surface of adsorbents and crystal violet molecules become stronger, and more molecules of dye were attached to the

34**surface of adsorbents** leading to **the increase** of **adsorption capacity of the adsorbents.**

All of the parameters of Lang- muir equation

15**are reasonable and consistent with the physical meaning of** each **parameter. The**

value of KF increase as the adsorption temperature increased as seen in Table 3, suggests that at higher temperature the permeability of crystal violet onto the surface of the adsorbent is enhanced

11**due to** the **greater contribution of kinetic energy.** This supported by **the**

Fig. 10. Experimental Adsorption Data for Crystal Violet onto Composite 4B:5A and the fits of the (a) Langmuir, (b) Freundlich,

3**at initial crystal violet concentration of** 300 **mg/L,**

temperature 30, 50, and 70 °C. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.) Fig. 11. Experimental Adsorption Data for Crystal Violet dye onto Sodium Alginate and the fits of the (a) Langmuir, (b) Freundlich, 3**at initial crystal violet concentration of** 300 **mg/L,**

temperature 30, 50, and 70 °C. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.) Fig. 12. Experimental Adsorption Data for Crystal Violet dye onto Bentonite and the fits of the (a) Langmuir, (b) Freundlich,

3**at initial crystal violet concentration of** 300 **mg/L,**

temperature 30, 50, and 70 °C. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

8**Table 3 Langmuir and Freundlich Parameters** of Isotherm **Adsorption**

between Crystal Violet at

8**initial concentration of** 300 **mg/L** with Bentonite, Alginate **and**

Composites. Adsorbent Langmuir Isotherm KL (L/mg) q max (mg/g) R2

5**30 °C 50 °C 70 °C 30 °C 50 °C 70 °C 30 °C 50 °C 70 °C**

Bentonite (B) Alginate (A) 2B:5A 3B:5A 4B:5A 0.0025 0.0041 0.0200 0.0201 0.0438 0.0608 0.0251 0.0854 0.0050 0.0322 0.0084 459.6011 0.1036 127.1875 0.0648 263.1415 0.1279 308.8336 0.0965 462.6072 523.5270 541.9624 158.8212 218.9595 323.9668 378.3974 378.9189 466.3858 555.8119 601.9339 0.9513 0.9850 0.9899 0.9834 0.9775 0.9932 0.9702 0.9755 0.9837 0.9955 0.9733 0.9908 0.9977 0.9770 0.9912 Adsorbent Freundlich Isotherm KF ((mg/g)(L/mg)−n) n R2

5**30 °C 50 °C 70 °C 30 °C 50 °C 70 °C 30 °C 50 °C 70 °C**

Bentonite (B) Alginate (A) 2B:5A 3B:5A 4B:5A 2.5435 5.9991 14.2955 18.5869 23.8229 3.0493 6.1570 17.0558 25.3562 29.5136 4.4969 1.2251 6.4547 1.7339 17.8241 1.4082 33.2873 1.3654 36.3399 1.0386 1.2685 1.2710 1.8142 1.8285 1.4580 1.5452 1.4333 1.5101 1.0743 1.2821 0.9643 0.9898 0.9914 0.9941 0.9972 0.9779 0.9873 0.9940 0.9844 0.9935 0.9829 0.9869 0.9921 0.9921 0.9954 randomness degree parameter, that is n, the increases in n value as the temperature increased indicate higher random motion of the solute (crystal violet). Meanwhile, in the different context, the n value de- creases as the mass ratio of bentonite in the composite increased. Suggests that the sodium alginate is incorporated with bentonite hence resulted in more homogeneous surface sites. The n value also indicates the surface area of the adsorbent, where higher n value indicates the higher surface area. Based on Table 3, alginate has largest n value. However, it has lower adsorption capacity. The reason is that the composites can trap crystal violet dye molecules better than alginate and bentonite due to the complex layer that formed through the combination of bentonite-alginate. The results

> 11**indicate that increasing the temperature** facilitates **the penetration of** crystal violet **onto**

composite thus chemisorption was dominant in this case. The maximum adsorption capacity (based on Langmuir model) at the highest investigated temperature (70 °C) is decreasing in the trend of Alginate < 2B:5A < 3B:5A < Bentonite < 4B:5A, where the value is 218.9595, 378.3974, 466.3858, 541.9624, and 601.9339 mg/g, respectively. The adsorption capacity trend based on Freundlich model is Bentonite < Alginate < 2B:5A < 3B:5A < 4B:5A, where the value is 4.4969, 6.4547, 17.8241, 33.2873, and 36.3399 (mg/g)(L/mg)−n, respectively. The composite, especially 4B:5A, has higher adsorption capacity than that of alginate and bentonite. 3.5. Thermodynamics study The extensive thermodynamic properties for the adsorption of crystal violet onto various adsorbents are calculated

> 26**as Gibbs energy change (ΔG0, kJ/mol), enthalpy change (ΔH0, kJ/mol), and entropy change (ΔS0, kJ/mol K)** [36,37]. **The**

adsorption process is favorable (spontaneous) if the value of ΔG0 is negative. According to Debye- Huckel limiting law for neutral or weak charges adsorbates, the value of ΔG0 can be calculated as: ΔG0 = —RT lnKL (6) where R is the gas constant with the value of

> 25**8.314 J/mol K, T is the absolute temperature (K), and KL is the Langmuir constant (L/mol). The**

relationship between ΔG0 with ΔH0 and ΔS0 is expressed as: ΔG0 = ΔH0 − T ΔS0 (7) Substitution of Eq. (6) to Eq. (7) gives lnKL = − ΔH0 ΔS0 + RT R (8) The value of ΔH0 and ΔS0 can be obtained from the slope and in- terception from the plot of lnKL against 1

> 28**/T. The** calculated **thermodynamic parameters** values **are** tabulated **in Table 4. The** ΔG0 **value is negative for** all systems, **indicates** that **the** adsorption **process is spontaneous** [38]. **The**

increase in temperature leads to higher negative ΔG0 value. Hence the adsorption

> 11**process was favorable at** a **higher temperature. The positive value of**

ΔH0 for all systems

16**indicates that the adsorption** process **is endothermic.** Mean- while, **the positive value of**

ΔS0 for all system reflects the increased randomness at the solid-solution interface during adsorption. This also implies that the adsorption is irreversible. Therefore regeneration of the adsorbent is improbable [39]. 3.6. Removal of crystal violet dye from a real or simulated wastewater To study the potential application of the composites

3**for the removal of crystal violet from** industrial **wastewater, the**

adsorption experiment was also conducted using simulated wastewater. The simulated waste- water contains NaCl, NaCO3, Na2S2O3, Na2SO3, Na2SO4, CuSO4, KCl, K2CO3, KF, K2SO4, NH4Cl, chloramine, urea, tartrate, and crystal violet. The concentration of each chemical in simulated wastewater were Table 4 Thermodynamic Parameters for Crystal Violet Dye Adsorption by Using Bentonite, Alginate and Composites. Adsorbent T (°C) ΔG0 (kJ/mol) ΔH0 (kJ/mol) ΔS0 (kJ/mol K) Bentonite (B) 30 50 70 Alginate (A) 30 50 70 2B:5A 30 50 70 3B:5A 30 50 70 4B:5A 30 50 70 −17.4600 −19.9410 −23.2214 −22.7010 −24.2121 −30.3889 −24.6768 −27.1859 −29.0502 −23.2735 −28.0987 −30.9901 −19.2070 −25.4782 −30.1864 26.0718 34.7900 8.5756 35.5292 64.2619 0.1432 0.1874 0.1100 0.1949 0.2761 Fig. 13. Removal of crystal violet from simulated wastewater. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.) 100 ppm, while for the crystal violet was 300 ppm. The experimental result of the adsorption of crystal violet from simulated wastewater is depicted in Fig. 13. High percent removal of crystal violet indicates that the composite (4B:5A) has potential application in industrial scale wastewater treatment. 4. Conclusion Bentonite – alginate composites were synthesized from acid – acti- vated bentonite and sodium alginate. Based on the FTIR and XRD analysis indicated that the alginate molecules did not intercalate to silicate layers of bentonite, the bonding between alginate and bentonite only through the electrostatic interaction between positively charged of bentonite with carboxyl group of sodium alginate. The

21**pseudo-first and pseudo-second order** equations **were** employed **to correlate the** ad- sorption **kinetic** results, and **pseudo-second order** could represent **the experimental data**

better than pseudo-first order.

12**Chemisorption is dominant and controls the adsorption as rate-limiting step.**

Both Langmuir and Freundlich equation could

7represent the adsorption data well with reasonable and consistent values of parameters.

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