

Coal fly ash-slag and slag-based geopolymer as an absorbent for the removal of methylene blue in wastewater

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ABSTRACT

The fly ash and slag from coal burning were attractive byproducts to prepare geopolymers for the adsorption of methylene blue in wastewater due to their availability and low cost. Various mixing amounts between them were conducted during geopolymerization with a Na₂SiO₃/NaOH ratio of 10 M of 2.5 and a curing temperature of 60°C for 24 h. When the amount of coal slag in the geopolymer composition was increased from 0 to 51 %, the surface structures of the resultant geopolymers were much softer and more porous due to the lack of initial material, causing a reduction in the surface area of geopolymers to 119,23 m²/g for 0 % and 5,29 m²/g for 51 %. The adsorption amount of methylene blue performed at pH 12 showed different tendencies on the dependence of contact time for the individually prepared geopolymer. The uptake amount decreased from 36.2 mg/g to 34.2 mg/g with the enhancement of coal slag in the geopolymer from 0 to 51 % after 180 minutes of immersion in methylene blue solution. In addition, the adsorption mechanism evaluated by FT-IR spectroscopy was observed to involve electrostatic forces formed by hydrogen bonding between hydroxyl groups (Si-OH) and nitrogen atoms in the structure of methylene molecules. This study indicated that coal slag could be a potential material to prepare geopolymers for removing dye pollutants.

Key words: adsorption, coal fly ash, coal slag, geopolymer, methylene blue

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INTRODUCTION

Dyes are important compounds commonly used in various industries, such as textile, paper, leather and plastic manufacturing. The textile industry is a focus of pollution; this industry produces 8000 kg/day per fabric and consumes approximately 1.6 million liters of water per day¹. The discharge of dye-containing effluent without proper treatment into water causes environmental and health damage. Approximately 50 % of dyes are released to the environment as pollutants because of the low interaction between fibers and dyes². This dye easily binds with other compounds, has a slow biodegradation rate, and has a high level of color³. This high concentration of inorganic dyes in the environment will decrease the ecosystem quality because it inhibits sunlight and disrupts biological processes in water⁴. In addition, it is highly toxic and may damage the landscape of the affected environment. Among the textile dyes most used in industry, methylene blue (MB) is a water-soluble cationic dye and can reveal very harmful effects on living things, such as difficulties in breathing, vomiting, diarrhea, nausea and several negative impacts on the aquatic environment. Therefore, it is necessary to reduce the dye concentration in wastewater⁵. The

method to remove dyes from wastewater that has attracted much attention due to its high simplicity, environmental friendliness, low cost and potential efficiency is adsorption. The goal is to find a desirable adsorption material regenerated from industrial wastes or byproducts for the degradation of hazardous substances from wastewater. Geopolymers are inorganic polymers and are a new class of synthetic aluminosilicate materials that involve a chemical reaction between alumina-silicate oxides and alkali metal silicate solutions under highly alkaline conditions^{6,7}. Depending on the different Si/Al ratios, the geopolymers are composed of three-dimensional network structures of polysialate (-O-Si-O-Al-O-), polysialate siloxo (-O-Si-O-Al-O-Si-O-), and polysialate disiloxo (O-Si-O-Al-O-Si-O-Si-O-). The initial ratio of Si/Al in the raw material from 3.0 to 3.8 could offer a very important role in the mechanical strength of the conducted geopolymer⁸⁻¹⁰. There are many studies about the preparation and properties of geopolymers with different synthesis conditions and adsorption applications^{1,11-15}. Normally, the starting material with a high content of SiO₂ and Al₂O₃ is favored for geopolymerization, for example, coal fly ash^{16,17}, steel slag^{18,19}, rice husk²⁰, etc. During

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the formation process, the activators, such as high-concentration alkali solution (NaOH, KOH, ...) and the binder sodium silicate (Na_2SiO_3), would be added to the mixture in the presence of the material¹⁰. It was found that geopolymers activated with NaOH gave higher compressive strength than those activated with KOH at the same concentration²¹. The concentration of the alkali solution was recommended in the wide range from 5 to 15 M²². Increasing the concentration of the alkali activator was able to enhance the dissolution of the silicate and alumino compounds in the raw material, which could optimize the bonding regeneration in the three-dimensional structure of the geopolymer. However, it was seen that the concentration of the NaOH solution was suitable at 10 M for the mechanical properties such as compressive and flexural strength of the synthesized geopolymer⁹. Additionally, the strength decreased after curing at temperatures over 80°C because the higher temperature could breakdown the structure of the geopolymer during hydration and overshrinkage²³. The best and most suitable temperature for the geopolymer process was 60 – 80°C²⁴. The higher concentration of NaOH was attributed to alumino-silicate gel precipitation at the early stage⁹. In addition, the ratio of NaOH/ Na_2SiO_3 was approximately 2.5^{9,25}. The role of the binder is to increase the amount of silica in the paste and support the formation of the Si–O–Si linkage. This bond produces a wider area than the others in the geopolymer structures¹⁰. Most of the studies have focused on coal fly ash. It is known that the chemical composition of coal slag is similar to that of fly ash. Nevertheless, coal slag-based geopolymers have not been well investigated. According to all of these, in the present study, the coal fly ash geopolymer was prepared in the addition of different amounts of slag to study the effect on the characterization of the mixed geopolymer and the adsorption ability of MB at various contact times. In addition, the adsorption mechanism was also proposed.

MATERIALS-METHODS

Materials

The coal fly ash (FA) and slag (S) generated from coal in the incinerator in this study were collected from Thuan Thanh Ltd. Company in Tân Tao Industrial Zone, Ho Chi Minh City (Figure 1). These samples were ground and sieved through a 245- μm sieve. After that, the pretreated FA and S were dried at 105°C for 24 h. Their chemical compositions measured by X-ray fluorescence (XRF) are presented in Table 1. As a result, the FA and S used were classified into class C

with low CaO content according to the ASTM C618 standard. Figure 2 shows the SEM micrograph of the raw material at 1000 \times for FA and S. The SEM images were observed by JSM-IT200 InTouchScope, JEOL after gold sputtering of their powders. The FA contained spherical particles 48 μm in diameter. However, impure matter was also detected. In contrast, the S particles were irregularly shaped with a diameter of approximately 200 μm . Hydrochloric acid (HCl, 36 %), sodium hydroxide (NaOH, 99 %), sodium silicate (Na_2SiO_3 , SiO_2 : 28.5 % and Na_2O : 8.5 %) and methylene blue (MB) were purchased from Merck, Germany. All chemicals used in the preparation of geopolymer and the adsorption experiment of MB were of analytical grade.

Methods

Geopolymerization

The pretreated fly ash and slag were mixed with the appropriate amount in the addition to NaOH and Na_2SiO_3 aqueous solution. The ratio between Na_2SiO_3 /NaOH was kept at 2.5. The loading of slag was varied in the range of 0 to 51 wt %, as noted as 51FA0S, 45FA6S, 30FA21S and 0FA51S. The paste was mixed within 5 minutes at room temperature before pouring into the steel mold ($\phi = 53 \text{ mm}$, $D = 33 \text{ mm}$) (followed by drying at 60°C for 24 h. After that, geopolymers were obtained (Figure 3). Before measurements, these samples were ground and washed in an excess amount of deionized water until the pH reached a neutral value.

Characterization

The transformation of the raw material to geopolymer after the activation of alkali solution was evaluated by Fourier transform infrared spectroscopy (FT-IR) (Microscope LUMOS, Bricker, Germany). The dried samples were ground with potassium bromide (KBr) in the transmittance model. The spectra were taken from 4000 to 600 cm^{-1} wavenumbers with a resolution of 2 cm^{-1} . In addition, the geopolymer used after MB adsorption was also checked to observe the differences in the spectrum.

The Brunauer–Emmett–Teller (BET) surface area and the pore size distribution of the geopolymer samples were measured by the Tristar II Surface area and porosity (Shimadzu). The geopolymer powders were dried under vacuum conditions over 24 h before nitrogen gas adsorption at 77 K.

The pH point of zero charge (pH_{pzc}) was determined to determine the adsorption performance of geopolymers depending on the solution pH. Approximately

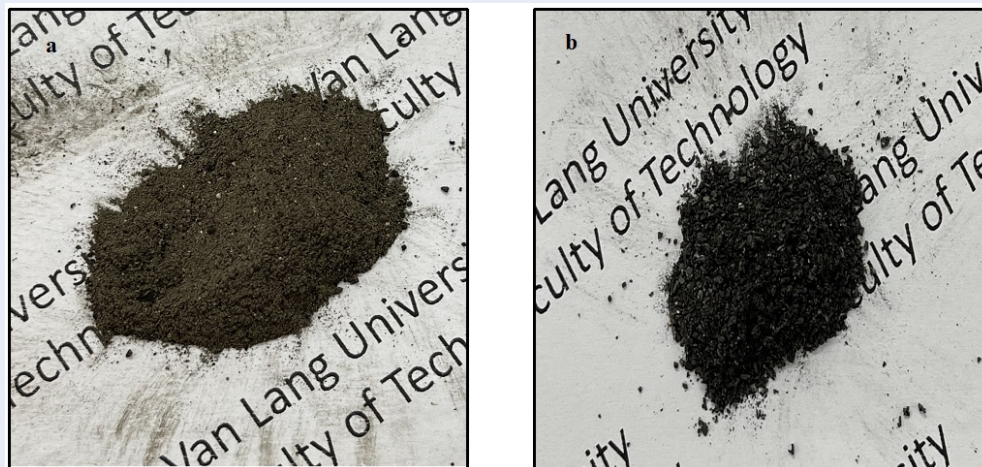


Figure 1: Appearance of (a) FA and (b) S

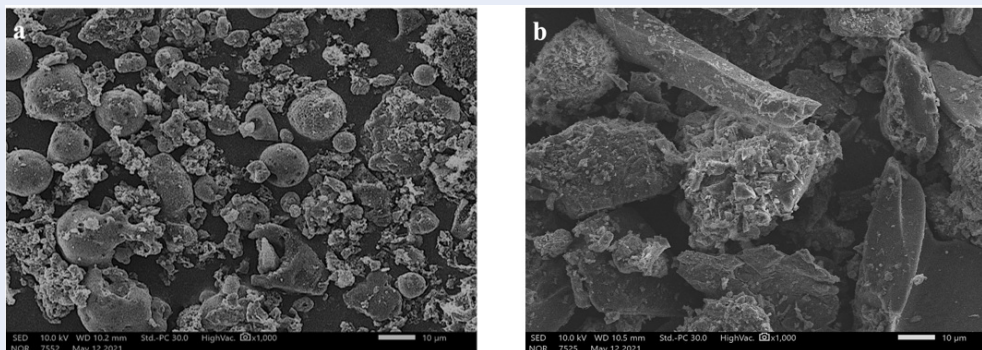


Figure 2: SEM micrographs at 1000× of (a) FA and (b) S

Table 1: Chemical composition (%) of FA and S

Sample	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	TiO ₂	MnO	P ₂ O ₅	SO ₃	LOI
FA	31.3	14.5	12.1	10.5	2.8	0.5	0.8	0.8	0.4	0.1	2.4	22.7
S	19.6	12	30.1	6.5	1.8	0.3	1.8	0.5	0.4	0.2	2.3	24.5

0.05 g of geopolymer was placed in glass Erlenmeyer flask containing 20 mL of 0.1 M aqueous solution, followed by pH adjustment at 2, 4, 6, 8, 10 and 12 (pH_i) by 1 N NaOH and 1 N HCl aqueous solution. The agitation time was 180 minutes 300 rpm at 27°C. After that, the final pH (pH_f) of the solution was measured for each sample. The pH_{pzc} values were calculated when the ΔpH was 0.

Adsorption experiment of MB

Stock MB solutions of 1000 mg/L were prepared by dissolving in deionized water. The working solution was diluted to the desired concentration. The adsorp-

tion of MB to geopolymer samples was measured by the following process. Approximately 0.05 g of the dry powder of geopolymer as an adsorbent was immersed directly into glass flasks containing 20 mL of initial solutions of 100 mg/L. The pH of the MB solutions adjusted by 1 M NaOH aqueous solution was kept at 12. After 3 h of agitation at 300 rpm at 27°C, the samples were centrifuged at 8000 rpm for 15 minutes to remove the adsorbed powders. After that, the remaining concentration of MB in the centrifuged solution was determined by UV-Vis spectrometry (PG Instrument, T60) at a wavenumber of 664 nm.

Here, the removal percentage (H %) was:

$$H (\%) = \frac{C_0 - C_t}{C_0} \times 100 \quad (1)$$

where H is the removal capacity of the MB absorbed at equilibrium (%), and C_0 and C_t are the initial and the time concentrations of MB in the solution (mg/L), respectively. M is the weight of the absorbents (g), and V is the volume of the solutions (L).

The uptake amounts q_t of MB to the geopolymer were calculated by the following equation:

$$q_t = \frac{C_0 - C_t}{M} \times V \quad (2)$$

where q_t is the amount of MB absorbed at equilibrium (mg/g)

RESULTS AND DISCUSSION

Appearance of geopolymers

The prepared geopolymers are shown in Figure 3. Sample 51FA0S had a dense surface. However, when 21 % S was added, the surface structure of the resultant geopolymer was porous. It is known that SiO_2 content plays an important role in the strength of the obtained geopolymers. Increasing the loading of S in the geopolymer would cause the soft structure of the materials²⁶. On the other hand, the slag-based geopolymer with 51 % S was not well-conducted due to the deficient interaction between the coal slag and the additives. Therefore, the mold could not be completely removed in shape.

After preparation, geopolymers were ground and washed with deionized water until reaching neutral pH prior to further measurements.

Properties of geopolymers

In the present study, the morphologies of the prepared geopolymers were evaluated by SEM to observe the differences in the surface structure of the materials used. It was clear that the active reagents, such as NaOH, caused a strong influence on the surface of FA and S. Figure 4 shows the surface particles of geopolymers 51FA0S and 30FA21S. There was a difference in the case of the initial FA and 51FA0S samples. After the activation of a strong alkali aqueous solution and adding binder, the surface structure of the FA particles was rougher, as seen at a magnification of 5000 \times . However, several raw FA particles remained after geopolymerization (1000 \times). With the addition of S at 21 % as sample 30FA21S, the geopolymer particles seemed to be in the sponge shape. Overall, these morphologies were expected to have high surface areas for

the potential adsorption of contaminants in wastewater.

The FT-IR spectra of the initial materials (FA, S) and the prepared geopolymers (51FA0S, 30FA21S) are shown in Figure 5. In general, the 3400 – 3500 cm^{-1} area was the O–H group of silanol (Si–OH) forming on SiO_2 ²⁷. The peak at 1650 cm^{-1} was attributed to H–O–H owing to the bouncing of the free water molecules on the materials, suggesting the hydrating property^{9,28}. In the case of raw FA, the vibration at 788 cm^{-1} was typical for Al–O²⁹, while the vibration at 1102 cm^{-1} was typical for asymmetric stretching of Si–O–Si⁹. After the geopolymerization process, there was a new peak at 1002 cm^{-1} representing the formation of Al–O–Si for 51FA0S. In addition, the C = O group in Na_2CO_3 was observed at 1456 cm^{-1} due to the activation of NaOH vs Na_2SiO_3 solutions^{9,27}. When the coal slag was loaded at 21 % in the geopolymer as 30FA21S, the appearance of Al–O–Si linkage was seen at 1004 cm^{-1} , and C=O was shifted to the higher wavelength of 1482 cm^{-1} . Therefore, the geopolymer structure was confirmed when FA and S were treated with alkali and binder solutions.

To evaluate the porosity of the materials, nitrogen isotherm adsorption-desorption was used to measure the surface area. Figure 6 illustrates the nitrogen adsorption-desorption at isotherm conditions, while the relative pressure (P/P_0) ranged from 0 to 1. The geopolymer sample exhibited the type-IV curve behavior³⁰, indicating the mesoporous property in the material structure. It was shown that the nitrogen adsorption amount was decreased when the amount of S in the raw mixture was enhanced, expecting that the surface areas of the related geopolymers were reduced. The surface areas of the synthesized samples are listed in Table 2. When the loading of coal S was increased from 0 to 51 %, the surface areas of geopolymers were 119,23 m^2/g for 51FA0S and 5,29 m^2/g for 0FA51S. The SEM micrographs suggested that after geopolymerization by the alkali solution, the surface morphology of the 51FA0S particle was strongly affected, leading to the rough observation. Nevertheless, coal S did not seem to be well-reacted with the additives. Hence, the surface area of 0FA51S was lower than those of the others.

pH_{pzc} is the value of pH providing zero charge on the sample surface. When the pH of the solution was lower than pH_{pzc} , the surface charge was positive, resulting in good anion adsorption. Meanwhile, the negatively charged surface was predominant when the pH of the solution was higher than pH_{pzc} , which suggested better cation attraction. In Figure 7, the pH_{pzc} values of 51FA0S and 0FA51S were 8 and 7.4,

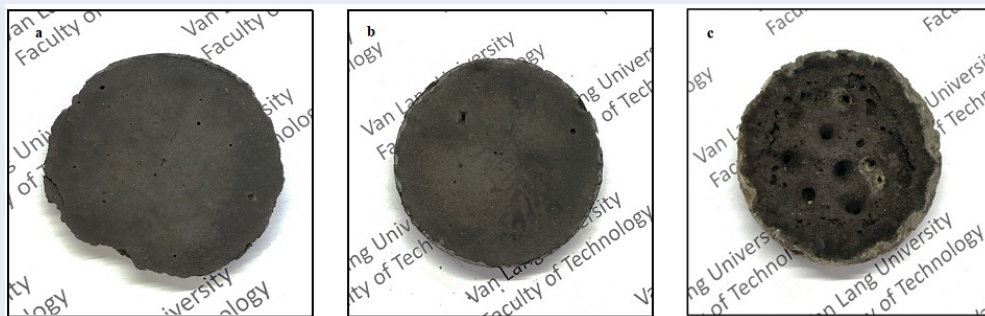


Figure 3: Appearance of geopolymer (a) 51FA0S, (b) 45FA6S and (c) 30FA21S

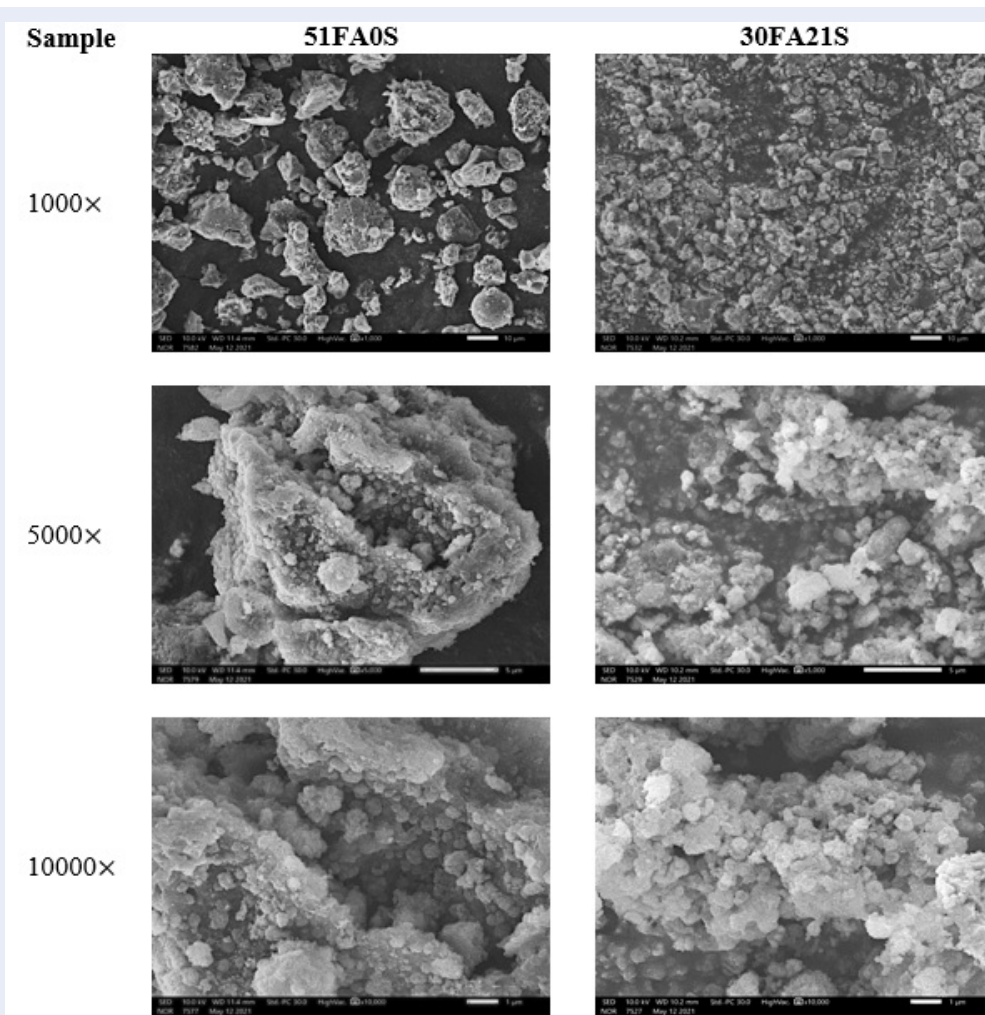


Figure 4: SEM images of geopolymer particles of 51FA0S and 30FA21S

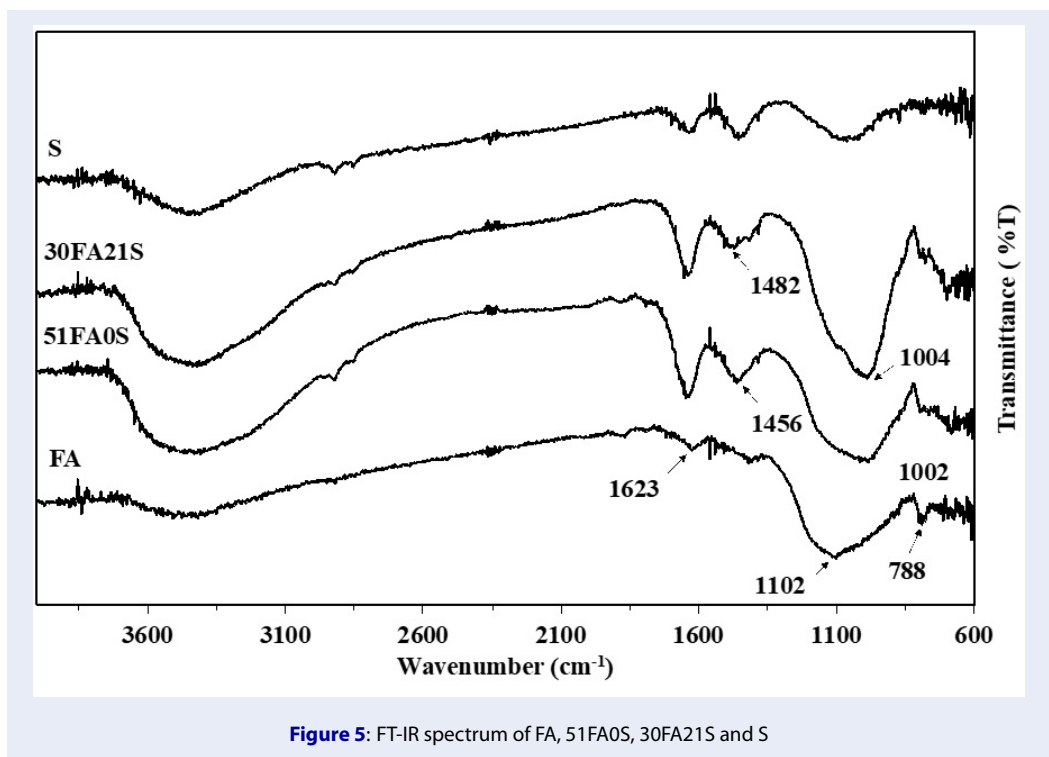


Figure 5: FT-IR spectrum of FA, 51FA0S, 30FA21S and S

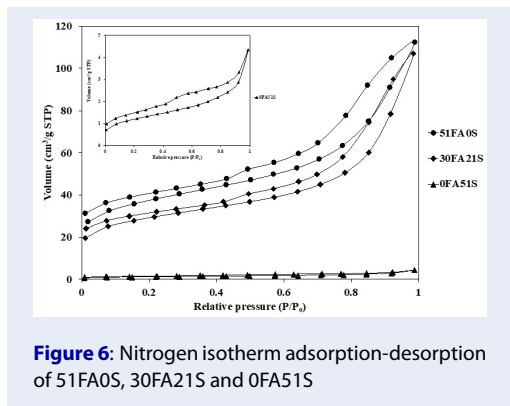


Figure 6: Nitrogen isotherm adsorption-desorption of 51FA0S, 30FA21S and 0FA51S

respectively. When S was loaded in the geopolymer material, the values of pH_{pzc} were not significantly different, as they were 8.2 for 45FA6S and 8.4 for 30FA21S. Therefore, the result indicated that the geopolymer surface was negatively charged when the pH of the solution was higher than 7.4. It is known that the geopolymer structure is composed of silicate (SiO_2) and alumina (AlO_4) with covalent linkages of Si-O-Al. The negative charge on the material surface was the effect of $(-Si-O-Al^- -O-Si-O)^5$. Hence, this meant that the adsorption of MB by geopolymer could be enhanced at pH values higher than 8 because MB molecules were associated with cations in aqueous so-

lution³¹.

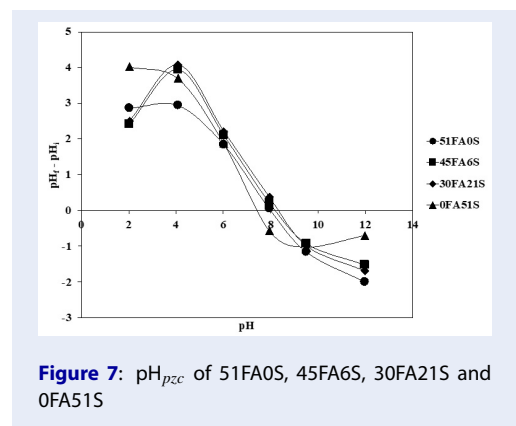


Figure 7: pH_{pzc} of 51FA0S, 45FA6S, 30FA21S and 0FA51S

Methylene blue adsorption by geopolymer

The adsorption of MB solution was performed with an initial concentration of 100 mg/L and pH 12 at 27°C, and the contact time was in the range of 15, 30, 45, 90, 120, 150, 180 and 210 minutes. Figure 8 shows the dependence of the q_t value of the geopolymer versus the contact time. When the contact time was increased from 15 to 180 minutes, the adsorption capacity gradually increased. For example, the

q_t value of 51FA0S was 30 mg/g at 15 min and 30.8 mg/g at 90 min of uptake. When the removal time was 180 minutes, the adsorption capacity was 36.2 mg/g. However, a similar adsorption amount of 36 mg/g was obtained when the longer contact time was 210. After shaking within 180 minutes, the removal capacity was almost in equilibrium. Therefore, 180 minutes was used as the optimal contact time in the MB adsorption experiment. The loading of coal S in the geopolymer composition could influence the removal efficiency. The adsorption tendency was not similar in the case of the FA-geopolymer. In the case of the coal slag-based geopolymer 0FA51S, the adsorption amount was rapidly enhanced from 17.3 mg/g to 26.6 mg/g after treatment for 15 and 90 minutes. This could be due to the difference in pore size distribution in the S-geopolymer. After 180 minutes of contact time, the q_t of 0FA51S was 34.2 mg/g and decreased to 33.1 mg/g for a longer adsorption time of 210 minutes. Overall, the uptake amounts of 0FA51S were lower than those of 51FA0S. This could be because the value of the surface area of 51FA0S was significantly higher than that of 0FA51S, leading to better MB adsorption. For the mixed geopolymer, when the S was increased from 6 to 21 %, the adsorption amount after 90 minutes was constant at approximately 29 mg/g. The uptake capacity was enhanced to 34.7 and 32.6 mg/g for 45FA6S and 30FA21S, respectively, after 180 minutes of shaking.

It could be seen from these results that the addition of coal S to the geopolymer component did not significantly affect the removal efficiency of MB in aqueous solution.

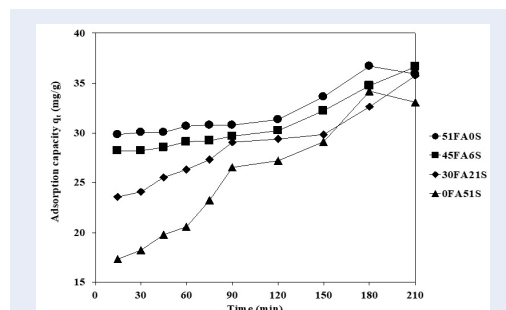


Figure 8: The effect of time contact on the MB adsorption of geopolymer

The adsorption mechanism of geopolymer toward MB

The MB molecule was associated with cations in aqueous solution, whereas the geopolymer network was

negatively charged due to the presence of Al in the IV-fold structure. Therefore, the electrostatic interaction between the geopolymer surface and the MB cation was suspected³². Oxygen groups, such as hydroxyl (-OH), were formed on the edges of the Si ion. This could provide a strong affinity by hydrogen bonding between the hydroxyl group and nitrogen atom in the MB molecule or the -Si-O- linkage and MB cation. In the case of ion exchange, Na⁺ ions in the geopolymer structure balance the negative charge caused by tetrahedron Al⁻³³. Hence, the MB-adsorption mechanism was cation exchange by Na⁺ ions in the geopolymer network.

In this research, MB uptake on the geopolymer was observed by FT-IR spectroscopy. Sample 51FA0S was measured after immersion in 100 mg/L MB aqueous solution for 3 h with agitation at 300 rpm at 27°C. The pH of the solution was kept at 12. The sample was coded as 51FA0S-MB. In Figure 9, the IR spectrum of 51FA0S-MB showed that the wavelength of 3241 cm⁻¹ was the vibration of N-H, indicating that the MB molecule was adsorbed on the geopolymer sample. This could be due to the hydrogen-bonding interaction between the hydroxyl group -OH in Si-O and the nitrogen atom in the MB structure. As a result, this mechanism was suggested by the peak shifting in the case of geopolymer to the higher wavelength (1002 cm⁻¹ for 51FA0S and 1005 cm⁻¹ for 51FA0S-MB)³⁴.

CONCLUSIONS

Coal fly ash- and slag-based geopolymers with various mixing amounts from 0 to 51 % were successfully prepared in the presence of a NaOH/Na₂SiO₃ aqueous solution ratio of 2.5, and the curing temperature was 60°C for 24 h. When the loading amount of coal slag in the geopolymer composition was increased from 0 to 51 %, the pH_{pzc} values decreased from 8 to 7.4, followed by a reduction in the surface area to 119,23 m²/g for 51FA0S and 5,29 m²/g for 0FA51S. In the methylene blue adsorption experiment at pH 12, the results showed that the addition of coal slag to the geopolymer structure did not significantly affect the adsorption capacities after immersing the adsorbent in MB solution within 180 minutes. Based on these results, coal slag could be a useful material to synthesize a potential adsorbent to increase the value of this byproduct and the economic benefits.

COMPETING INTEREST

The author(s) declare that they have no competing interest.

Table 2: The adsorption capacity q_t (mg/g) of MB by geopolymer at different contact times

Sample	Time (minute)									
	15	30	45	60	75	90	120	150	180	210
51FA0	29.9	30.1	30.1	30.7	30.8	30.8	31.3	33.6	36.2	36.0
45FA6S	28.2	28.2	28.5	29.1	29.2	29.7	30.2	32.3	34.7	36.6
30FA21S	23.6	24.1	25.5	26.3	27.3	29.1	29.4	29.8	32.6	35.8
0FA51S	17.3	18.2	19.8	20.6	23.3	26.5	27.2	29.1	34.2	33.1

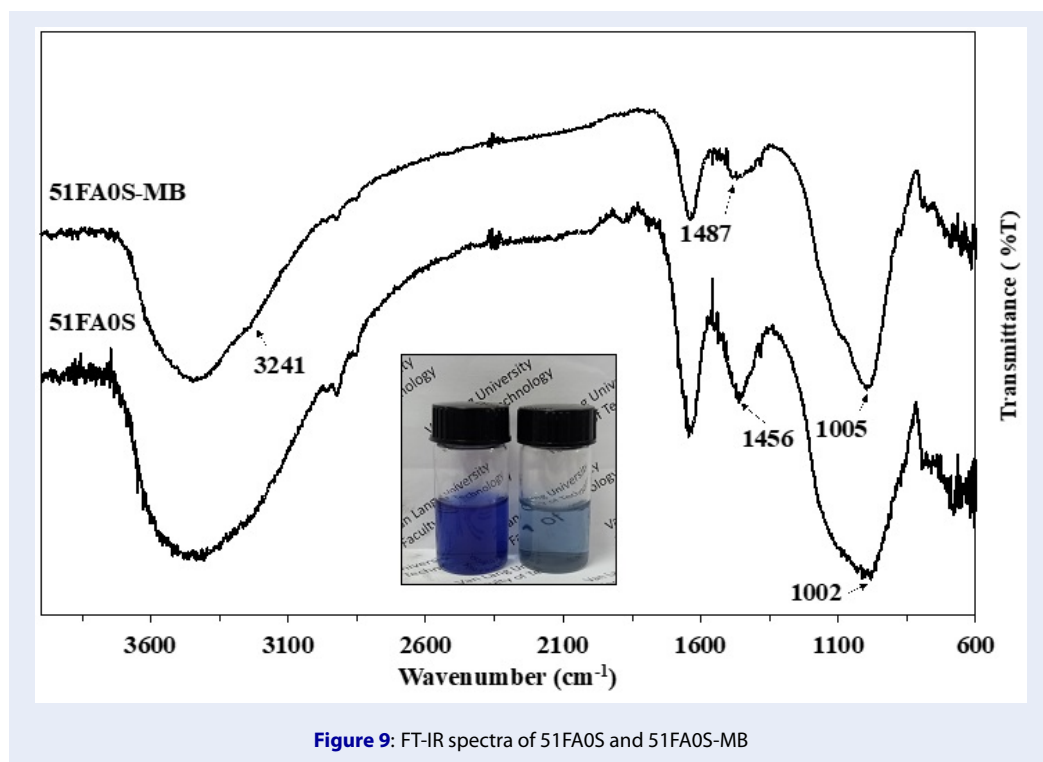


Figure 9: FT-IR spectra of 51FA0S and 51FA0S-MB

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REFERENCES

- Pinto LF, Montaño AM, González CP, Barón GC. Removal of rhodamine B in wastewater from the textile industry using geopolymeric material. *Journal of Physics: Conference Series*. 2019;1386:012040; Available from: <https://doi.org/10.1088/1742-6596/1386/1/012040>.
- Salleh MAM, Mahmoud DK, Karim WAWA, Idris A. Cationic and anionic dye adsorption by agricultural solid wastes: A comprehensive review. *Desalination*. 2011;280(1):1-13; Available from: <https://doi.org/10.1016/j.desal.2011.07.019>.
- Ma G, Zhu Y, Zhang Z, Li L. Preparation and characterization of multi-walled carbon nanotube/TiO2 composites: Decontamination organic pollutant in water. *Applied Surface Science*. 2014;313:817-22; Available from: <https://doi.org/10.1016/j.apsusc.2014.06.079>.
- Chen Q, He Q, Lv M, Xu Y, Yang H, Liu X, et al. Selective adsorption of cationic dyes by UiO-66-NH2. *Applied Surface Science*. 2015;327:77-85; Available from: <https://doi.org/10.1016/j.apsusc.2014.11.103>.
- M. EL Alouani SA, M. EL Achouri, M. Taibi. Removal of Cationic Dye - Methylene Blue from Aqueous Solution by Adsorption on Fly Ash-based Geopolymer. *Journal of Materials and Environmental Sciences*. 2019;9(1):32-46; Available from: <https://doi.org/10.26872/jmes.2018.9.1.5>.
- Davidovits J. Geopolymers - Inorganic polymeric new materials. *Journal of Thermal Analysis*. 1991;37:1633-56; Available from: <https://doi.org/10.1007/BF01912193>.
- Onutai S, Kobayashi T, Thavorniti P, Jiemsirilers S. Porous fly ash-based geopolymer composite fiber as an adsorbent for removal of heavy metal ions from wastewater. *Materials Letters*. 2019;236:30-3; Available from: <https://doi.org/10.1016/j.matlet.2018.10.035>.
- Davidovits J, editor *Properties of geopolymer cements*. First international conference on alkaline cements and concretes; 1994;.
- Onutai S, Jiemsirilers S, Thavorniti P, Kobayashi T. Aluminium hydroxide waste based geopolymer composed of fly ash for sustainable cement materials. *Construction and Building Ma-*

- terials. 2015;101:298-308;Available from: <https://doi.org/10.1016/j.conbuildmat.2015.10.097>.
10. Onutai S, editor Development of geopolimer materials sourced with fly ash and industrial waste 2016;.
 11. Novais RM, Carvalheiras J, Tobaldi DM, Seabra MP, Pullar RC, Labrincha JA. Synthesis of porous biomass fly ash-based geopolimer spheres for efficient removal of methylene blue from wastewaters. *Journal of Cleaner Production*. 2019;207:350-62; Available from: <https://doi.org/10.1016/j.jclepro.2018.09.265>.
 12. Maleki A, Mohammad M, Emdadi Z, Asim N, Azizi M, Safaei J. Adsorbent materials based on a geopolimer paste for dye removal from aqueous solutions. *Arabian Journal of Chemistry*. 2020;13(1):3017-25; Available from: <https://doi.org/10.1016/j.arabjc.2018.08.011>.
 13. Rasaki SA, Bingxue Z, Guarecuco R, Thomas T, Minghui Y. Geopolimer for use in heavy metals adsorption, and advanced oxidative processes: A critical review. *Journal of Cleaner Production*. 2019;213:42-58; Available from: <https://doi.org/10.1016/j.jclepro.2018.12.145>.
 14. Cheng TW, Lee ML, Ko MS, Ueng TH, Yang SF. The heavy metal adsorption characteristics on metakaolin-based geopolimer. *Applied Clay Science*. 2012;56:90-6; Available from: <https://doi.org/10.1016/j.clay.2011.11.027>.
 15. Medri V, Papa E, Mor M, Vaccari A, Natali Murri A, Piotte L, et al. Mechanical strength and cationic dye adsorption ability of metakaolin-based geopolimer spheres. *Applied Clay Science*. 2020;193:105678; Available from: <https://doi.org/10.1016/j.clay.2020.105678>.
 16. P. Chindapasirt TC, V. Sirivivatnanon. Workability and strength of coarse high calcium fly ash geopolimer Cem Concr Compos. 2007;29:224-9; Available from: <https://doi.org/10.1016/j.cemconcomp.2006.11.002>.
 17. Nyale SM, Babajide OO, Birch GD, Böke N, Petrik LF. Synthesis and Characterization of Coal Fly Ash-based Foamed Geopolimer. *Procedia Environmental Sciences*. 2013;18:722-30; Available from: <https://doi.org/10.1016/j.proenv.2013.04.098>.
 18. Abdel-Ghani NT, Elsayed HA, AbdelMoied S. Geopolimer synthesis by the alkali-activation of blastfurnace steel slag and its fire-resistance. *HBRC Journal*. 2018;14(2):159-64; Available from: <https://doi.org/10.1016/j.hbrj.2016.06.001>.
 19. Bai T, Song Z-G, Wu Y-G, Hu X-D, Bai H. Influence of steel slag on the mechanical properties and curing time of metakaolin geopolimer. *Ceramics International*. 2018;44(13):15706-13; Available from: <https://doi.org/10.1016/j.ceramint.2018.05.243>.
 20. Detphan S, Chindapasirt P. Preparation of fly ash and rice husk ash geopolimer. *International Journal of Minerals, Metallurgy and Materials*. 2009;16(6):720-6;.
 21. Pimraksa K, Chindapasirt P, Rungchet A, Sagoe-Crentsil K, Sato T. Lightweight geopolimer made of highly porous siliceous materials with various Na₂O/Al₂O₃ and SiO₂/Al₂O₃ ratios. *Materials Science and Engineering: A*. 2011;528(21):6616-23; Available from: <https://doi.org/10.1016/j.msea.2011.04.044>.
 22. Onutai S, Jiemsirilerts S, Wada S, editors. Effect of Sodium hydroxide solution on the properties of Geopolimer based on fly ash and aluminium waste blend 2014;.
 23. Görhan G, Kürklü G. The influence of the NaOH solution on the properties of the fly ash-based geopolimer mortar cured at different temperatures. *Composites Part B: Engineering*. 2014;58:371-7; Available from: <https://doi.org/10.1016/j.compositesb.2013.10.082>.
 24. Yao X, Zhang Z, Zhu H, Chen Y. Geopolymerization process of alkali-metakaolin characterized by isothermal calorimetry. *Thermochimica Acta*. 2009;493(1):49-54; Available from: <https://doi.org/10.1016/j.tca.2009.04.002>.
 25. Nazari A, Bagheri A, Riahi S. Properties of geopolimer with seeded fly ash and rice husk bark ash. *Materials Science and Engineering: A*. 2011;528(24):7395-401; Available from: <https://doi.org/10.1016/j.msea.2011.06.027>.
 26. Arpita Bhatt SP, Aiswarya Acharath Mohanakrishnan, Arash Abri, Melanie Sattler, Sorakrich Techapaphawit., Physical, chemical, and geotechnical properties of coal fly ash: A global review. *Case Studies in Construction Materials*. 2019;11; Available from: <https://doi.org/10.1016/j.cscm.2019.e00263>.
 27. Sulistiyo YA, Andriana N, Piluharto B, Zulfikar Z. Silica Gels from Coal Fly Ash as Methylene Blue Adsorbent: Isotherm and Kinetic Studies. 2017. 2017:10; Available from: <https://doi.org/10.9767/bcrec.12.2.766.263-272>.
 28. Kumar S, Kristály F, Mucsi G. Geopolymerisation behaviour of size fractionated fly ash. *Advanced Powder Technology*. 2015;26(1):24-30; Available from: <https://doi.org/10.1016/j.apt.2014.09.001>.
 29. Damayanti NP. Preparation of superhydrophobic PET fabric from Al₂O₃-SiO₂ hybrid: geometrical approach to create high contact angle surface from low contact angle materials. *Journal of Sol-Gel Science and Technology*. 2010;56(1):47-52; Available from: <https://doi.org/10.1007/s10971-010-2271-0>.
 30. Thommes M, Kaneko K, Neimark AV, Olivier JP, Rodriguez-Reinoso F, Rouquerol J, et al. Physisorption of gases, with special reference to the evaluation of surface area and pore size distribution (IUPAC Technical Report). *Pure and Applied Chemistry*. 2015;87(9-10):1051-69; Available from: <https://doi.org/10.1515/pac-2014-1117>.
 31. Ali Maleki JS. Adsorbent materials based on a geopolimer paste for dye removal from aqueous solutions. *Arabian Journal of Chemistry*. 2020;13:3017-25; Available from: <https://doi.org/10.1016/j.arabjc.2018.08.011>.
 32. El Alouani M, Alehyen S, El Achouri M, Taibi Mh. Preparation, Characterization, and Application of Metakaolin-Based Geopolimer for Removal of Methylene Blue from Aqueous Solution. *Journal of Chemistry*. 2019;2019:4212901; Available from: <https://doi.org/10.1155/2019/4212901>.
 33. Al-Ghouthi MA KM, Nasser MS, Al Saad K, Ee Heng O Application of geopolymers synthesized from incinerated municipal solid waste ashes for the removal of cationic dye from water. *PLoS ONE*. 2020;15(11):e0239095; PMID: 33151952. Available from: <https://doi.org/10.1371/journal.pone.0239095>.
 34. Piotr Rożek Magdalena K, Włodzimierz Mozgawa. Lightweight geopolimer-expanded glass composites for removal of methylene blue from aqueous solutions. *Ceramics International*. 2020;46:19785-91; Available from: <https://doi.org/10.1016/j.ceramint.2020.05.011>.

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