**ABSTRACT**

The silica@mercapto (HS@M) hybrid adsorbent was successfully synthesized from Takari sand and modified with mercapto. The HS@M was synthesized using the sol-gel method. FTIR results showed that HS@M had been successfully prepared by showing the presence of groups of hydroxyl (-OH), silanol (Si-OH), siloxane (Si-O-Si), methylene (-CH₂), and thiol (-SH) with the peak of 3426.33 cm⁻¹, 2936.62 cm⁻¹ and 2553.39 respectively. It also showed the interaction in HS@M-Cu(II) and HS@M-Pb(II), indicated by the disappearance of silanol, siloxane, and thiol groups. There was also a new absorption band at 797.2 cm⁻¹. XRF results showed that there were two major substances in HS@M, which were Si and S with each percentage of 31.7% and 59.6%. The surface morphology imaged by SEM showed there were amorphous granules on the surface of HS@M. The mapping analysis showed there was a homogenous distribution of granules on the surface of HS@M. Optimum acidity for Cu(II) and Pb(II) adsorption was at pH 5. The optimum contact time of Cu(II) was 50 min and that of Pb(II) was 80 min. The optimum concentration of Cu(II) was 80 mg/L and that of Pb(II) was 20 mg/L. Finally, the adsorption kinetics of both ions followed pseudo-second-order.

**Keywords:** Silica-mercapto, Natural Sand, Adsorption Kinetics, Takari-Timor

**INTRODUCTION**

Heavy metal ions in the ecosystem have a serious dangerous impact on all living organisms if exposed for a long time because they are toxic, cumulative, and uncompostable.¹,² Examples of heavy metals that could harm the environment are Fe, Cr, Hg, Cd, Ni, Zn, Mn, Cu, and Pb.³⁻⁴ Owing to the toxicity of these metals, the WHO restricts the maximum acceptable concentrations of Cu and Pb ions in drinking water to be 2.0 and 0.01 mg/L, respectively.⁵ If people consume water consisting of Cu(II) and Pb(II) above the normal level, they will cause some disadvantages like vomiting, gastric ulcer, colic, hypotension, liver necrosis, and even comma.⁵,⁶ Hence, there should be an action to minimalize the concentration of Cu(II) and Pb(II) in the water.

There are some methods to eliminate the presence of heavy metals chemically such as chemical precipitation, solvent extraction, coagulation, complexion, ion exchange, membrane separation, and adsorption.³,⁷,⁸ Based on the aforementioned methods, the adsorption method is the most effective one to...
decrease the concentration of heavy metals in the water.\textsuperscript{4,9} This method has advantages compared to the others, i.e. its simple process, environmentally-friendly, no toxic substances produced, and high effectivity and efficiency.\textsuperscript{5,9,10,11} Adsorption is an efficient and economical option.\textsuperscript{12,13} Known adsorbents that are popularly used are active carbons,\textsuperscript{9,14} clays,\textsuperscript{15} bentonites,\textsuperscript{9} zeolites,\textsuperscript{16} ion exchange resins\textsuperscript{17}, and silicas.\textsuperscript{18} Silicas themselves are the most utilized adsorbent.\textsuperscript{19} Taking the potential of the sand of Nusa Tenggara Timur, especially Timor island, into account, this paper reports the use of natural-based silica from the sand of Nusa Tenggara Timur. Based on Naat et al. (2018), the percentage of SiO\textsubscript{2} extracted from Takari sand is 97.8\%.\textsuperscript{20} This high percentage shows that the sand could be used for more researches and development.

Silica gel is one of the materials which is used as an adsorbent.\textsuperscript{7,21} This material is an ideal supporting solid because of its resistance to swelling, stability in an acidic environment, high mass exchange characteristic, porosity, surface area, and high resistance to heat.\textsuperscript{22} Silica gel is also used as the primary material to produce an adsorbent that can adsorb heavy metal ions or dangerous and poisonous pollutants because silica gel has functional groups of Si-OH and Si-O-Si.\textsuperscript{23,24} However, this material is not that effective in adsorbing metal ions because the oxygen atoms as silanol and siloxane are not effective as the electron pair donors. This will lead to a weak chemical bond of metal ions to the surface of silica gel.\textsuperscript{25} This low ability is caused by the direct bond between oxygen and silicon atoms in the silica network.\textsuperscript{23} Atom O in the silica is also small in size and has low polarisability.\textsuperscript{26} One of the ways to solve this problem is by modifying organic compounds containing active functional groups such as –OH, –NH, COOH, and -SH that will produce hybrid organosilica.\textsuperscript{21,27} Modification of the surface area of silica gel can be done by adding organic functional groups that could act as a complexing agent to heavy metals directly or indirectly using an intermediate.\textsuperscript{28,29} Therefore, modification of active surface area of silica gel is importantly needed to increase the metal ions adsorption effectivity by adding other active functional groups such as -SH (mercapto). Mercapto (-SH) is a functional group found in organosilane compounds and this group can be utilized to modify silica. This paper reports the modification of HS@M that was conducted via the sol-gel process. This process is one of the ways to modify the surface of silica chemically in the preparation of hybrid-organosilica material through the homogeneous pathway.\textsuperscript{8,20} The sol-gel method has advantages i.e. able to be prepared at low temperature, homogenous, and can be mixed well in the multi-component system.\textsuperscript{30,31} This article is declared the extraction of silica from the sand of Takari-East Nusa Tenggara, using the wet method. Afterward, the silica was modified with mercapto from a precursor compound, 3-mercaptopropyltrimethoxysilane (3-MPTMS), to produce the hybrid adsorbent silica@mercapto (HS@M) using the sol-gel method. Characterizations were conducted using SEM to capture the morphology image of HS@M and FTIR to collect the IR spectra of silica, HS@M, and HS@M-Pb(II). This paper also reports the optimization of parameters and kinetics models of copper(II) and lead(II) using HS@M.

**EXPERIMENTAL**

**Reagent and Materials**

Merckapropil-trimetoksisilan (3-MPTMS, 97%-ABCR), nitric acid (HNO\textsubscript{3}, purists. p.a., ≥65%), acetic acid (CH\textsubscript{3}COOH, 100% (v/v)), Hydrochloric acid (HCl 37%), and Copper(II) sulfate pentahydrate (CuSO\textsubscript{4}.5H\textsubscript{2}O, ACS reagent, ≥98.0%), Pb(NO\textsubscript{3})\textsubscript{2} (greater than 98% purity from Merck), Sodium hydroxide (NaOH) purists. p.a.) was purchased from Sigma Aldrich (Singapore). Aqua demineralization was produced in our lab. The natural sand was collected from Takari-Timor Island-NTT.

**Silica Extraction**

Takari sand was washed with aquadest and processed using a wide stirrer. The sand was dried in an oven at 105°C for 2 h. The sand was be mashed using a disk mill at 200 mesh. 50 g of sand was soaked with 2 M HCl for 12 h. The sand was filtered, dried and the result is mixed until the powder is homogeneous. 4 g of sand powder was diluted in 60 mL of 7 M NaOH and refluxed at 90°C using a magnetic stirrer until sodium silicate was formed. The mixture was mixed in 60 mL of aquadest for 24 h. The results are filtered and titrated with HCl until reached pH 7. The precipitation was dried and cleaned using aquadest.\textsuperscript{20,32}

**Preparation of Hybrid Adsorbent Silica@Mercapto (HS@M)**

HS@M was prepared from 20 mL of sodium silicate from extracted sand that was mixed with 8 mL of 3-MPTMS. The mixing process was done in 2 h using a magnetic stirrer. 3 M of HCl was dropped slowly in
the mixing process until the solution became neutral (pH 7). The formed gel was set aside for 24 h. The gel was washed and dried at 70°C for 2 h. The dried gel was then crushed and filtered using 200 mesh filter to finally prepare HS@M.

**Analysis and Characterization**

The HS@M were characterized using XRF (PANalytical, type: minipal-4 merk), SEM (FEI type Inspect-S50 merk), FTIR (type Prestige-21 Shimadzu), Cu(II), and Pb(II) was determined using AAS AA-7000 Shimadzu series.

**Optimation of pH of Cu(II) and Pb(II) Adsorption**

0.1 g of HS@M was mixed with 25 mL of 5 mg/L Cu(II) at various acidities, which were pH 2, 4, 5, 6, and 7. The mixture was stirred with a shaker at 300 rpm for 50 min. The mixture was filtered and analyzed with AAS. The same procedure was conducted to optimize the pH of Pb(II) adsorption.

**Optimation of Adsorption Time of Cu(II) and Pb(II)**

0.1 g of HS@M was mixed with 25 mL of 5 mg/L Cu(II) at optimum pH. The contact time was studied from 10 to 80 min using a shaker (300 rpm). The mixture was filtered and analyzed with AAS. The same procedure was conducted to optimize the time of Pb(II) adsorption.

**Optimation of Concentration of Cu(II) and Pb(II)**

0.1 g of HS@M was mixed with 25 mL of Cu(II) at various concentrations i.e. 20, 40, 60, 80, 100, and 120 mg/L at optimum time and pH. The mixture was stirred at 300 rpm. The mixture was filtered and analyzed with AAS to determine the concentration of the rest of the metal ions. The metal ions adsorbed were calculated using the eq. (1) as follows: \[ q = \frac{(C_0-C_t) \cdot V}{m} \] (1)

\( C_0 \) (mg/L): the initial concentration of the sample, \( C_t \) (mg/L): the analyte concentration at time \( t \) (minutes), \( V \) (L): the sample volume, and \( m \) (g): the adsorbent mass. The adsorption efficiency at optimum condition was calculated using eq. (2): \[ \%E_p = \frac{(C_{initial} - C_{final})}{C_{initial}} \times 100\% \] (2)

**Adsorption Kinetics Analysis**

The analysis was conducted by mixing 0.1 g of HS@M with 25 mL of 5 mg/L Pb(II) and Cu(II) respectively with the variations of stirring time of 10, 20, 30, 40, 50, and 60 min for Pb(II) and 30, 40, 50, 60, 70, and 80 min for Cu(II). The stirring processes were conducted at optimum pH at 300 rpm. The mixtures were analyzed using AAS. Adsorption kinetics models are this process were: pseudo-first-order, pseudo-second-order, Elovich, and Bangham model. The pseudo-first-order is expressed using the following eq. (3): \[ \ln (q_e - q_t) = \ln q_e - kt \] (3)

The data acquired from \( \ln (q_e - q_0) \) and \( t \) were plotted to obtain the value of \( k \), \( q_e \), and \( R^2 \). Pseudo-second order is expressed using the following eq. (4):

\[ \frac{t}{q_t} = \frac{1}{kq_e^2} + \frac{1}{q_e} t \] (4)

Elovich model was expressed using the following eq. (5):

\[ q_t = \frac{1}{\beta} \ln (\alpha \beta) + \frac{1}{\beta} \ln t \] (5)

The data collected from \( q_t \) and \( \ln t \) were plotted to obtain the value of \( \beta \), \( \alpha \), and \( R^2 \). Bangham model was expressed using the following eq. (6):

\[ \log (\log \frac{C_0}{C_0 - q_t}) = \log (\frac{K_m}{2.303V}) + \alpha \log t \] (6)
The data collected from \( \log \left( \frac{c_0 - q_t}{c_0 - q_m} \right) \) and \( \log t \) were plotted to obtain the value of \( k_m \) and \( R^2 \). A suitable kinetics adsorption model was described as fit by evaluating the \( R^2 \) value of each equation. The model with the closest value to 1 was considered fitted to describe the adsorption process.

**RESULTS AND DISCUSSION**

**Characterization of HS@M using FTIR**

Figure-1 showed the FTIR spectra of extracted silica, HS@M, and HS@M-Pb(II). There was a stretching vibration of –OH in Si-OH at 3436.90 cm\(^{-1}\) and also a stretching vibration of Si-O in Si-OH at 946.96 cm\(^{-1}\). These vibrations are the characteristics of silanol groups.

![FTIR Spectra of Silica extracted Silica, HS@M, and HS@M-Pb(II)](image)

There was an asymmetric stretching vibration from Si-O of siloxane (Si-O-Si). Si-O also gave symmetric stretching vibration at 797.22 cm\(^{-1}\) while there was a bending vibration at 467.87 cm\(^{-1}\). The absorption band at 1627.79 cm\(^{-1}\) showed a bending vibration of Si-O from Si-OH. Based on Fig.-1 shows that the silica had been successfully extracted from the natural sand of Timor. FTIR characterization of HS@M (red peak) showed the decrease of absorption band from 3436.90 cm\(^{-1}\) to 3426.33 cm\(^{-1}\). These bands indicated the presence of stretching vibration of O-H from mercapto in HS@M. The wide and sharp absorption band at 2936.62 cm\(^{-1}\) indicated the stretching vibration of \( \text{CH}_2 \) of 3-MPTMS. The success of the modification process of silica with 3-MPTMS could be seen with the presence of -SH on the spectra which was the unique characteristic of mercapto\(^{25}\). The absorption band at 2553.49 cm\(^{-1}\) showed the asymmetric stretching vibration of –SH where organic compounds that have a functional group like –SH will weakly absorb FTIR at 2600-2550 cm\(^{-1}\) \(^{36}\). The absorption band at 1627.79 cm\(^{-1}\) indicated the stretching vibration of –OH from water molecules. The absorption band at 1351.23 cm\(^{-1}\) and 1404.08 cm\(^{-1}\) – 1450.22 cm\(^{-1}\) were the vibration of -C-C- from the methylene group (-CH\(_2\)). Absorption bands at 1244.66 – 1297.50 cm\(^{-1}\) possibly indicated the stretching vibration of NO\(_2\) and C-N amine/amide. The band at 914.37 cm\(^{-1}\) indicated the stretching vibration of Si-O from Si-OH. Absorption at 691.53 cm\(^{-1}\) showed the stretching vibration of C-S and the band at 468.82 cm\(^{-1}\) showed the bending vibration of Si-O-Si. The formation of the HS@M complex would be indicated by the shift of wavelength number for some functional groups. Fig.-1 showed that Pb(II) was adsorbed by HS@M, proven by the shift of wavelength number from 3426.33 cm\(^{-1}\) to 2936.62 cm\(^{-1}\) which was the vibration of –CH\(_2\). The band also indicated that Pb(II) was bound with –SH via mercapto.

**Characterization of HS@M with X-Ray Fluorescence**

The characterization using XRF was conducted to determine the composition of HS@M. A diffractogram of HS@M of this characterization was shown in Fig.-2.
Figure-2 showed that the substances with the highest percentage were sulfur 59.6% and silicon 31.7%. Substances with the percentage below 10% were Mo (7.4%), Ca (0.75%), La (0.25%), Fe (0.16%), and Cu (0.074%). The result indicated that the modification of silica with mercapto showed by the presence of sulfur which was the main functional group of mercapto (SH) from HS@M.

**Morphology Characterization of HS@M using SEM**

SEM image in Fig.-3 showed that there were irregular granules on the surface of HS@M and there were also particles that formed the bigger size of aggregates. The surface of HS@M was dominated by sulfur (S) with a percentage of 59.6% while the percentage of silicon (Si) was 31.7%. These images from Fig.-4 was indicated that the modification of HS@M was synthesized successfully. The distribution of substances such as Si, O, and S on the surface of HS@M was indicated in a different color (Fig.-4). Figure-4a is the distribution of substance on the HS@M surface. The dark-purple, dark-green color, and green-colored were identified as Si atoms, O atoms, and S respectively (Fig.-4b to Fig.-4d). The dark-green part showed the presence of O atoms (Fig.-4c), and S (Fig.-4d) on the surface of HS@M indicated by the green-colored. These result images indicated that the substances were distributed spread evenly on the surface of HS@M.
Parameters of Adsorption
Optimation of pH of Cu(II) and Pb(II) adsorption
Fig.-5 showed the relationship between pH and the number of adsorbed Cu(II) and Pb(II). Based on Fig.-5, HS@M at pH 2-4 only adsorbed an extremely small number of Cu(II) and Pb(II). This was caused by the competition between the metal ions and H\(^+\) at that low acidity. The adsorption of both metal ions reached its optimum condition at pH 5. There was no more competition between the ions and H\(^+\) in this acidity. The surface of the adsorbent was not protonated so that it became negatively charged. This charge then released the protons from other functional groups to increase the interaction with Cu(II) and Pb(II). At that acidity, the active site of HS@M consisting -SH that was neutral and the functional groups of silanol (-OH) and siloxane (Si-O-Si) were negatively charged that supported them to be the electron pair donors that could interact with ion Cu(II) and Pb(II) by forming coordination covalent bonds.

Optimation of contact time of Cu(II) and Pb(II)
Figure-6 showed that the optimum condition for the contact time of Cu(II) adsorption was 50 min and 80 min for Pb(II). Below the optimum condition, there was a smaller number of functional groups that adsorbed Cu(II) and Pb(II) due to the adsorption equilibrium factor between HS@M and the ions did not reach its optimum condition and also due to the contact time that did not optimum yet for the adsorbent to interact with the ions. The longer the contact time, the higher the number of Cu(II) and Pb(II) adsorbed by thiol groups to form complex groups. At the optimum point, the adsorption power of Cu(II) and Pb(II) would reach 1.185 mg/g and 1.311 mg/g respectively. This was caused by the interaction between functional
groups of adsorbent and metal ions that reached its equilibrium where active sites of HS@M were full of ions that made them no longer able to absorb more ions. When the contact time had reached its optimum condition, there was a decrease in the adsorption process because the function groups of adsorbent had reached their constant condition in interacting with the ions.

![Fig.-6: Optimization Curve of Contact Time and adsorption](image)

**Optimization of Initial Concentration of Cu(II) and Pb(II)**

Table-1 and Fig.-7 showed the efficiency of adsorption and the condition of optimum concentration of ions adsorption by HS@M.

<table>
<thead>
<tr>
<th>Initial Concentration (C₀) (mg/L)</th>
<th>Adsorption Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cu(II)</td>
</tr>
<tr>
<td>10</td>
<td>97.312</td>
</tr>
<tr>
<td>20</td>
<td>97.471</td>
</tr>
<tr>
<td>40</td>
<td>97.942</td>
</tr>
<tr>
<td>60</td>
<td>98.230</td>
</tr>
<tr>
<td>80</td>
<td>98.618</td>
</tr>
<tr>
<td>100</td>
<td>98.342</td>
</tr>
<tr>
<td>120</td>
<td>98.091</td>
</tr>
</tbody>
</table>

Based on Table-1, the graph of adsorbate concentration and the number of ions adsorbed could be plotted. Fig.-7 showed that the optimum concentration of Cu(II) was 80 mg/L and 20 mg/L for Pb(II). The efficiency of Cu(II) adsorption by HS@M increased at 20-80 mg/L and decreased at 100-120 mg/L. The optimum condition of adsorption concentration of Cu(II) was reached at 80 mg/L with the number of ions adsorbed was 19.72 mg/g and the adsorption efficiency was 98.62%. The adsorption process was decreased at 100-120 mg/L possibly because the surface of HS@M was saturated by the presence of ions. The optimum condition of adsorption concentration of Pb(II) was reached at 20 mg/L with the number of ions adsorbed was 4.97 mg/g and the adsorption efficiency was 99.56%. One of the possible reasons was the equilibrium had been reached when the equilibrium had been reached, Pb(II) could no longer be adsorbed significantly. At 10 mg/L, the concentration of Pb(II) was small compared to the number of bonding groups on the surface of HS@M so that the adsorption was still able to be increased. When the initial concentration was above 20 mg/L, the adsorption ability became weaker and the efficiency of adsorption was decreased.

**Adsorption Kinetics of Cu(II) and Pb(II)**

This paper reports four kinetics models used to describe the adsorption process of Cu(II) and Pb(II) which were pseudo-first-order (PFO), pseudo-second-order (PSO), Elovich model, and Bangham model. The graphs of kinetics models of Cu(II) and Pb(II) were shown in Fig.-8 and the kinetics parameters were shown in Table-2.
**Adsorption of Cu(II) and Pb(II)**

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**Fig.-7:** Optimization Curve of Initial Concentration Adsorption

**Fig.-8:** Kinetics Models Curve of Cu(II) and Pb(II) Adsorption: (a). PFO, (b). PSO, (c) Elovich, and (d) Bangham.

**Table-2:** The Values Kinetics Parameters of Cu(II) and Pb(II) adsorbed by HS@M

<table>
<thead>
<tr>
<th>Metal Ions</th>
<th>Kinetics Models</th>
<th>Parameters</th>
</tr>
</thead>
</table>
| Cu(II)     | Pseudo-first order | \( y = 0.0433x - 6.1166 \)  
R\(^2\) = 0.3858  
k\(_1\) = 0.009 g.mg\(^{-1}\).min\(^{-1}\)  
q\(_e\) = 39.777 mg.g\(^{-1}\) |
### Table 1: Kinetic Models for Cu(II) and Pb(II) Adsorption

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameters</th>
<th>Equations</th>
<th>$R^2$</th>
<th>Constants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pseudo-second order</strong></td>
<td>$y = 0.7983x + 1.638$</td>
<td>$k_2 = 0.3882 \text{ g.mg}^{-1} \text{.min}^{-1}$</td>
<td>0.9698</td>
<td>$q_e = 1.253 \text{ mg.g}^{-1}$</td>
</tr>
<tr>
<td><strong>Elovich</strong></td>
<td>$y = -0.0151x + 1.2688$</td>
<td>$\beta = 66.225 \text{ g.mg}^{-1}$, $\alpha = -4.861 \times 10^{-20} \text{ g.mg}^{-1} \text{.min}^{-1}$</td>
<td>0.9698</td>
<td></td>
</tr>
<tr>
<td><strong>Bangham</strong></td>
<td>$y = -0.0136x - 1.9516$</td>
<td></td>
<td>0.9698</td>
<td>$K_m = 6.436 \times 10^{-4} \text{ (mL/(g/mL))}$</td>
</tr>
<tr>
<td><strong>Pb(II)</strong> Pseudo-first order</td>
<td>$y = -0.0009x - 4.0215$</td>
<td>$k_1 = 0.0009 \text{ g.mg}^{-1} \text{.min}^{-1}$</td>
<td>0.9698</td>
<td>$q_e = 0.0179 \text{ mg.g}^{-1}$</td>
</tr>
<tr>
<td><strong>Pseudo-second order</strong></td>
<td>$y = 0.8123x - 0.4093$</td>
<td>$k_2 = -1.612 \text{ g.mg}^{-1} \text{.min}^{-1}$</td>
<td>1.0000</td>
<td>$q_e = 1.231 \text{ mg.g}^{-1}$</td>
</tr>
<tr>
<td><strong>Elovich</strong></td>
<td>$y = -0.0077x + 1.2751$</td>
<td>$\beta = -129.870 \text{ g.mg}^{-1}$, $\alpha = -9.299 \times 10^{-75} \text{ g mg}^{-1} \text{.min}^{-1}$</td>
<td>0.9698</td>
<td></td>
</tr>
<tr>
<td><strong>Bangham</strong></td>
<td>$y = -0.0062x - 1.9499$</td>
<td></td>
<td>0.9698</td>
<td>$K_m = 6.4615 \times 10^{-4} \text{ (mL/(g/mL))}$</td>
</tr>
</tbody>
</table>

Figure-8 and Table-2 showed that the adsorption of Cu(II) and Pb(II) by HS@M followed the kinetics model of PSO. This was concluded by the values of $R^2$ which were the closest one to 1. The values were 0.969 for Cu(II) and 1.000 for Pb(II). This indicated the capacity of adsorption was proportional to the number of active sites between adsorbent and adsorbate. These results showed that the possible mechanism of adsorption processes that happened was chemisorption where there were electron exchanges between Cu(II) and Pb(II). The constant of Cu(II) adsorption was 0.388 g.mg$^{-1}$ min$^{-1}$ which meant that 0.388 g of adsorbent was able to adsorb 1 mg adsorbate in 1 min. On the other hand, the constant of Pb(II) adsorption was -1.612 g.mg$^{-1}$ min$^{-1}$.

**CONCLUSION**

Characterization of FTIR showed the success of the preparation of HS@M by confirming the presence of OH groups from Si-OH and Si-O-Si, methylene (-CH$_2$-), thiol (-SH) with the absorption bands at 3426.33 cm$^{-1}$, 2936.62 cm$^{-1}$, and 2553.39. The adsorption was happened to form Cu(II)-@M/HS and Pb(II)-@M/HS, indicated by the elimination of silanol and siloxane groups from the spectra and the presence of a new absorption band at 797.2 cm$^{-1}$. XRF characterization of HS@M showed that there were two dominant substances, which were Si and S with the percentage of 31.7% and 59.6% respectively. SEM image showed that there were irregular granules on the surface of HS@M and also the presence of the bigger size of aggregates. The result of mapping showed a homogenous distribution on the surface of HS@M. The optimum pH of Cu(II) and Pb(II) adsorption was pH 5. The optimum contact time of Cu(II) was 50 min and 80 min for Pb(II). The optimum concentration of Cu(II) was 80 mg/L and 20 mg/L for Pb(II). Finally, the adsorption process of both ions followed the pseudo-second-order kinetics model.

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ADSORPTION OF Cu(II) AND Pb(II)

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