International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca
IJGE 2017 **3**(**4**): 125-130
Available at http://ojs.library.dal.ca/ijge
Section – Mineral Resources Extraction
Technical Note

Optimal Conditions for Treating Acid Mine Drainage using Bentonite-Steel Slag Composites

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Abstract: Acid mine drainage is characterised by low pH and high concentrations of heavy metal ions, such as Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+}. In this paper, composite particles consisting of bentonite and steel slags are used to dispose acid mine drainage. Bentonite is an mineral material which has an excellent capacity to adsorb heavy metal ions. Steel slags are alkaline, an industrial solid waste commonly used in the treatment of acid mine drainage. The main influencing factors, including adsorbent dosages, shaking rates, concentrations of heavy metal ions, temperature, adsorption time and pH value are examined using a static experiment. The results indicate that the removal efficiency of heavy metal ions improves when increasing the adsorbent dosages and the concentrations of the heavy metal ions, speeding up the shaking rates, raising temperature, extending the adsorption time and increasing pH value. With a consideration of removal efficiencies combining with treatment costs, the optimum reaction conditions for the four types of heavy metal ions are obtained, which are an adsorbent dosage of 21 mg/L, a rotational speed of 120 r/min, temperature 25℃, adsorption time 100 min and initial wastewater pH7. The highest initial concentration of Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} was 150 mg/L, 100 mg/L, 170 mg/L and 140 mg/L, respectively, and the removal rates was 93.42%, 92.64%, 93.86% and 95.17%, respectively, when the four heavy metal ions existed independently in the simulated mine wastewater. The determination of the particles' SEM-EDS Microscopic characterization show that the composite particles play a partial role in neutralizing, absorbing and the chemical precipitation. The acidity decreased notably and the heavy metal ions of Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} were adsorbed and precipitated effectively. The research results can extend the practical engineering application of the composite particles.

Keywords: Acid Mine Drainage, heavy metal ions, bentonite-steel slag composite particles, adsorb, precipitate, influencing factors, technologic conditions

1 Introduction

Environmental pollution from acid mine wastewater includes two aspects: acid wastewater and heavy metal ions. Accordingly, mine acid wastewater treatment is targeted at these two major components. Lei and Sun (2008) tested the separations of heavy mental precipitation using metal hydroxide and sulfide precipitation of different solubility products. Under the control of different precipitation conditions, specific ions were precipitated and separated. Peng (2010) explored the treatment of Fe^{2+}, Fe^{3+}, Mn^{2+} and Zn^{2+} in acid mine wastewater at two stages, neutralization of lime and sodium hydroxide. Xiao et al (2015) conducted shaking-absorption tests, a comparative experiment studied the effects of bentonite, steel slags, bentonite-steel slag composite powder materials, bentonite-steel slag composite particles on the treatment of acid mine wastewater containing Zn^{2+}. Xue et al (2013) investigated the adsorption removal of Cu(II) from aqueous solution by basic oxygen furnace slag (BOFs) which was activated by the mechanochemstry process. Rapacz-kmita et al (2016) examined the influence of the organophilisation process on the properties of resulting organobentonite fillers and their capability to improve the mechanical properties of clay/ polymer nanocomposites. Moreover, Shabani et al (2014) discussed the adsorption activity of perlite nanoparticles for removal of Cu^{2+}, Fe^{2+} and Mn^{2+} ions at Iran Sarcheshmeh copper acid mine drainage. Wang (2011) found that bentonite has highly adsorptive capacities with large internal surface areas. Yang et al (2010) consented that the special porous structures of steel slags not only have good adsorptive properties, but also have alkaline and mineral constituents of Ca_3SiO_5 and Ca_2SiO_4 etc. The hydrolyses of steel slags can release a large amount of alkalinity and neutralize the acid in mine wastewater. Wang et al (2010) also found that calcination could accelerate the evaporation of molecular water and organic when they are removed from the bentonite's surface and structure layers, the adsorption properties of the particles are enhanced.

In this experiment, bentonite and steel slags are mixed at a ratio of 5:5. The amount of binder of Na_2CO_3 is 5% of the total mass of the composite adsorbent, making of composite particles.

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DOI: 10.15273/ijge.2017.04.014

2 Test Section

2.1 Material

Sodium bentonite was bought from the shop of Wan Peng Bentonite mine located in Heishan county Liaoning Province. Slags were generated from a steel factory in Binzhou city, of Shandong Province. The agglomerant is $NaCO_3$. Heavy metal ions in the form of Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} are used in the simulated water.

2.2 Preparation of composite particles

To make bentonite-steel slag composite particles, bentonite and steel slags were mixed at a ratio of 5:5, of which the amount of binder of Na_2CO_3 was 5% of the total mass of the composite adsorbent. Distilled water was added into the mixture several times separately and stirred well with a glass rod. After vibrated and crushed using a heavy hammer, the composite materials were extruded to granulation. The diameter of the particles was 2 mm, and the calcination temperature was 500℃ for 1.5 hours.

2.3 Test methods

(1) Determination of optimum reaction conditions: The experiment contains four groups, each group includes 10 conical flasks with a capacity of 250 ml. Simulation of mine wastewater containing Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} by adding 100 ml distilled water to make, ions concentration of 100 mg/L, 35 mg/L, 20 mg/L and 25 mg/L, respectively. The prepared bentonite-steel slag composite particles were put into each conical flask, and then to seal the conical flask strictly. To study how the influencing factors, including the dosage of the adsorbent, shaking rate, temperature, adsorption time and pH, affect the removal of heavy metal ions, the residual concentrations of four heavy metal ions were measured under different reaction conditions. During the experiment, when a specified factor changed, other factors remain unchanged.
(2) Determination of the highest initial concentration of heavy metal ions: Under the above optimum reaction conditions, the other steps were also divided into four treatments, each treatment uses 10 conical flasks whose capacity is 250 ml. Simulation of mine wastewater contains only one ion of Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} by adding 100 ml distilled water, but their concentration was different. The residual metal ions concentrations were determined in each group. If the heavy metal ions were absorbed by the bentonite-steel slag composite particles above 90%, what the highest initial concentrations of the heavy metal ions were.
(3) SEM-EDS analysis of bentonite-steel slag composite particles could reveal morphological changes of the surface of composite particles before and after adsorption. The composite particles played a partial role in neutralizing, absorbing and the chemical precipitation.

3 Results and Discussions

3.1 Influencing factors on adsorption

(1) Effect of adsorbent dosage on adsorption
According to test method (1), pH of water samples was 7 and temperature of constant temperature oscillator was 25℃ with the speed of 120 r/min continuingly absorbing for 100 minutes. Under different dosages of composite adsorbent, the results of residual concentration and removal effects of the four heavy metal ions were obtained. The results are shown in Figure 1.

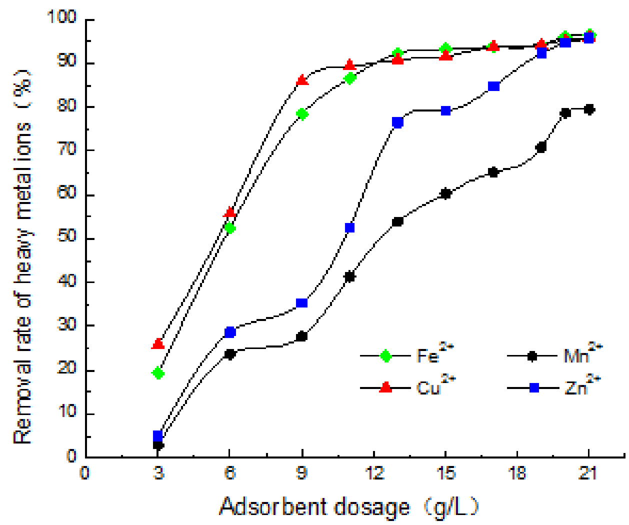


Figure 1. Effect of adsorbent dosage on adsorption

Figure 1 shows that, with an increasing of the dosages of the composite adsorbent of bentonite-steel slag, the removal rates of heavy metal ions increased gradually. When the adsorbent dosages were increased from 3 g/L to 13 g/L, the adsorption rates of Fe^{2+} and Cu^{2+} increased rapidly. With the adsorbent dosages increased to more than 13 g/L, the adsorption capacities of Fe^{2+} and Cu^{2+} remained constant. When the adsorbent dosages were between 3 g/L to19 g/L, the removal rates of Zn^{2+} maintained an obviously upward trend and the removal rates of Mn^{2+} increased steadily. The removal rates of the four heavy metal ions were gentle until the adsorbent dosages reached to 21 g/L.

This phenomenon has been explained by Fu et al (2009) that because the concentrations of Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} were given in solution, with the increase of the dosages of complex adsorbent, the adsorption capacities of heavy metal ions increased gradually, so the adsorption removal rates accordingly increased. Above all, the optimal dosage of the new composite adsorbent was 21 g/L.
(2) The shaking rate

When pH of water sample was 7, at different shock speeds, other test conditions followed the above. The results are shown in Figure 2.

From Figure 2, when the shaking rates increased from 0 r/min to 80 r/min, the overall removal rates showed upward trends. The removal rates of Mn^{2+} and Zn^{2+} increased faster than those of Fe^{2+} and Cu^{2+}. As the shaking rates were further increased from 80 r/min to 120 r/min, the removal rates of all four metal ions increased slowly.

As time went on, removal rates tended to become steady. If the shaking rates were too high, the strength of composite particles would be easily destroyed. Moreover, it will increase the costs of removing metal ions. In conclusion, the best shaking rate was 120 r/min.

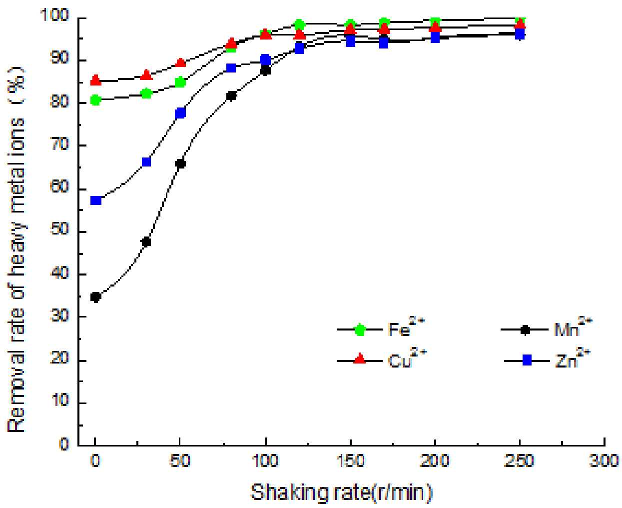


Figure 2. Effect of the shaking rate on adsorption.

(3) The temperature of the experiment

The shaking rate was set at 120 r/min, but at different temperatures, other test conditions followed the same as above. The results are shown in Figure 3.

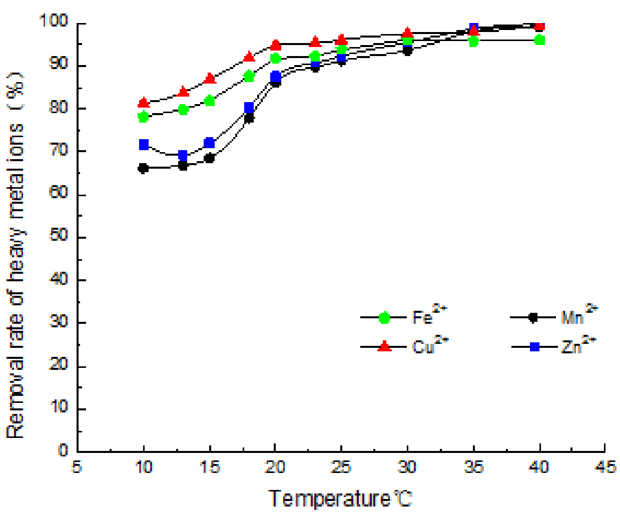


Figure 3. Effect of temperature on adsorption

As shown in Figure 3, the reaction temperatures of bentonite-steel slag composite particle adsorbent were elevated from 10℃ to 20℃, with removal rates of metal ions increased significantly. While the growth rates slowed down from 20℃ to 25℃, the removal rates kept constant after 25℃. Considering the treatment of actual water temperatures, the reaction temperature was identified as 25℃.

(4) The reaction time

The reaction temperature was set at 25℃ with different adsorption times, other test conditions followed the same setting. Figure 4 shows that, when the reaction time started from 10 to 50 min, the adsorption rates of Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} increased rapidly with the composite adsorbent. During the time period of 50 min to 100 min, the growth rates were slow down slightly, after 100 min the adsorption quantities tended to reach a steady level. The reason is that because the surface of composite particles contained material with adsorption effects, such as disconnect chemical bonds and hydroxyl radicals and so on, the metal ions could be adsorbed (Li 2011). The best reaction time was confirmed as 100 minutes by summarizing the experimental results.

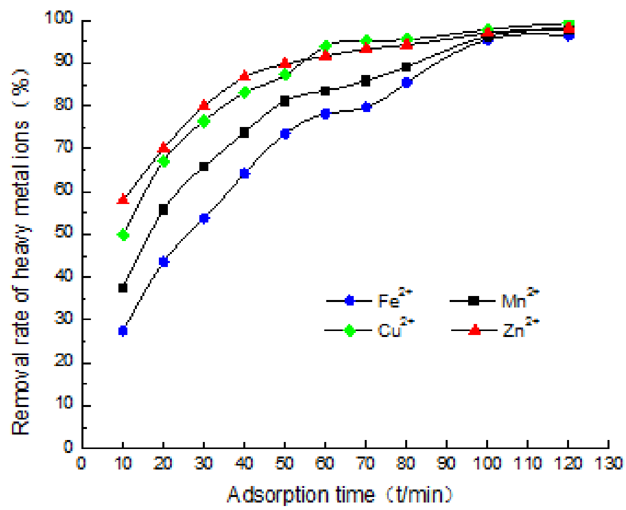


Figure 4. Effect of reaction time on adsorption.

(5) The initial wastewater pH

Adsorption of 100 min under different pH values, other test conditions followed the above, as shown in Figure 5.

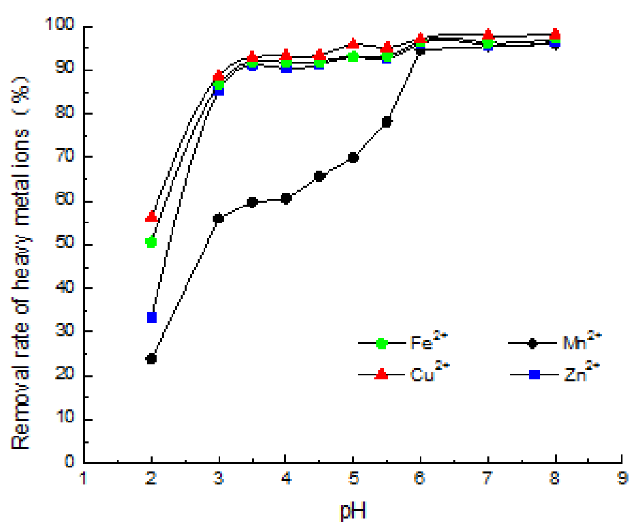


Figure 5. Effect of pH on adsorption

3.2 Effects of ions concentration on adsorption

According to Test method (2), based on the above optimum reaction conditions, the composite particle adsorbent of bentonite-steel slag was added to 21 g/L, pH of wastewater sample was 7 and temperature of constant temperature oscillator was 25℃ with the speed of 120 r/min continuing absorbing for 100 minutes. When the metal ions of Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} existed alone and the removal rates attained more than 90%, the highest initial concentrations of the four heavy metal ions were investigated. The results are shown in Figure 6.

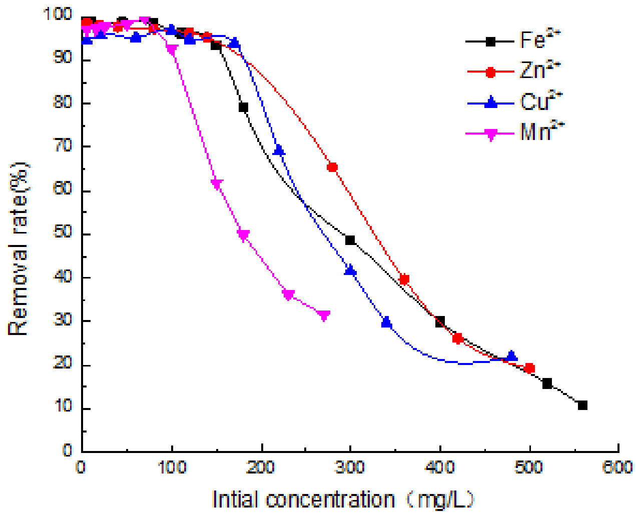


Figure 6. Removal rate of Fe^{2+}, Mn^{2+}, Cu^{2+}, Zn^{2+} at different initial concentrations

As shown in Figure 6, initially, the quantitative composite particle adsorbent can provide sufficient adsorption sites for metal ions. Therefore, the adsorption rates of metal ions were more than 90% by the composite adsorbent of bentonite-steel slag within a certain adsorption capacity range. Beyond that, adsorption removal rates decreased rapidly. When usages of the composite particle adsorbent were 21 g/L, the highest initial concentrations of Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} was 150 mg/L, 100 mg/L, 170 mg/L and 140 mg/L, respectively.

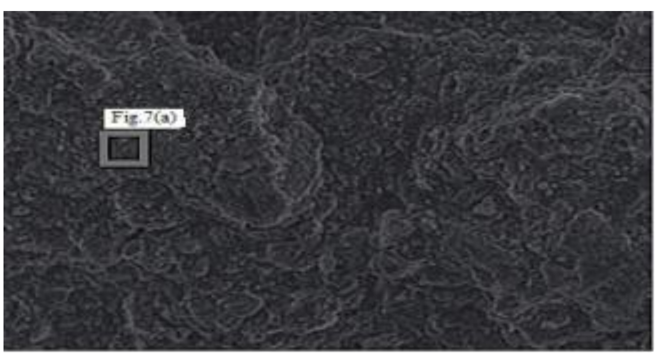
3.3 Structure and properties of composite particles

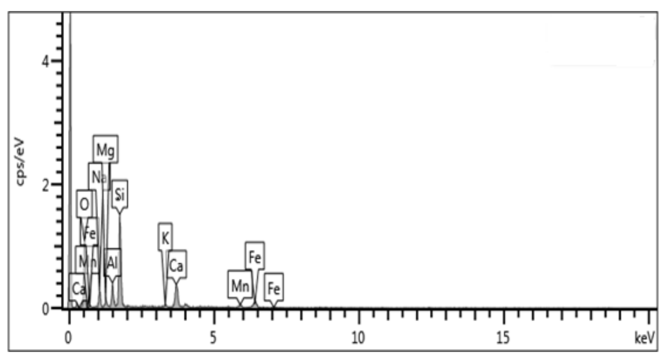
The configurations of particles were compared before and after adsorption. Through scanning electron microscope, SEM-EDS analyses of composite particles were obtained before reactions and after adsorbing Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+}. The results are shown in Figure 7.

Comparing the SEM diagrams before and after adsorption, the surface of the composite particles was uneven after the adsorption, parts of holes were blocked at the same time. Combining the EDS spectra, the contents of Fe and Mn in the surface of the composite particles were increased after adsorbing Fe^{2+} and Mn^{2+}. The elements of Cu and Zn were detected on the surface of Cu^{2+} and Zn^{2+} after adsorption. The specific surface areas of the composite adsorbent enlarged to continue absorbing and coagulating the ions.

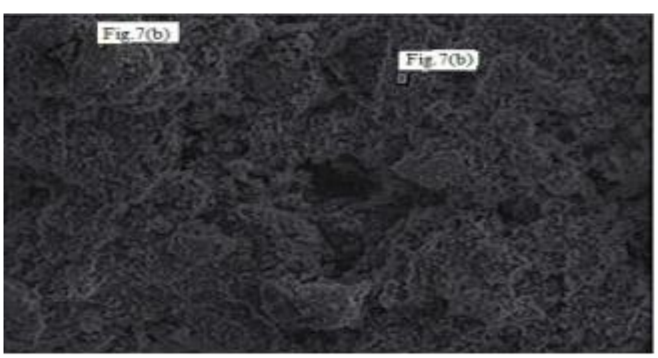
4 Conclusions

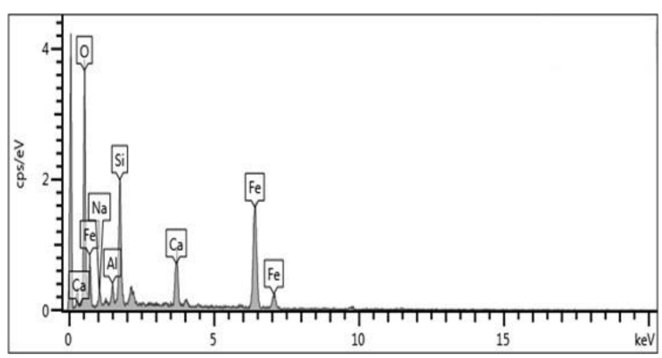
(1) This static experiment studies the main influencing factors. It provides the best reaction conditions in which the



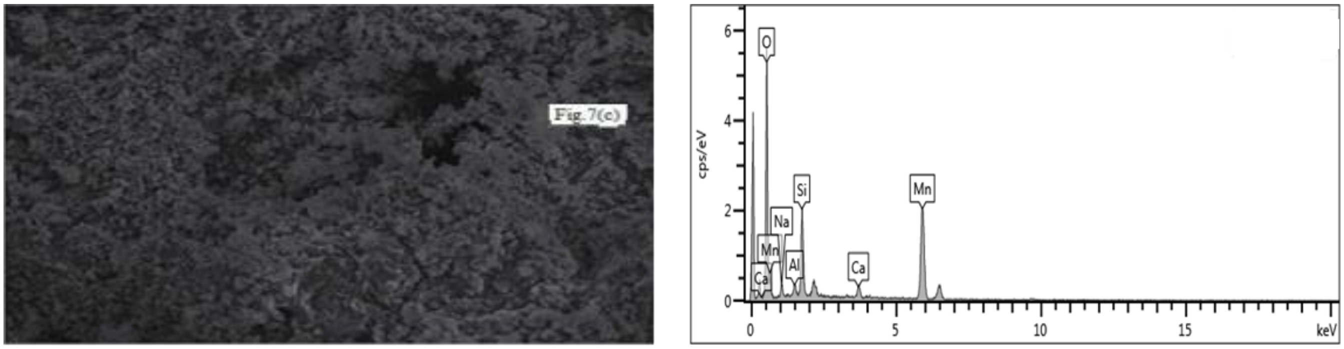


(1) SEM-EDS spectra of composite particles before adsorption

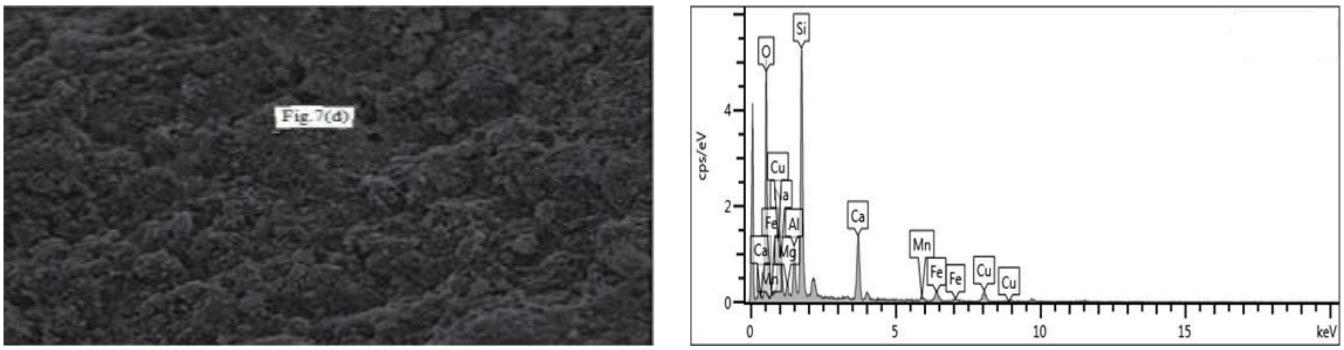




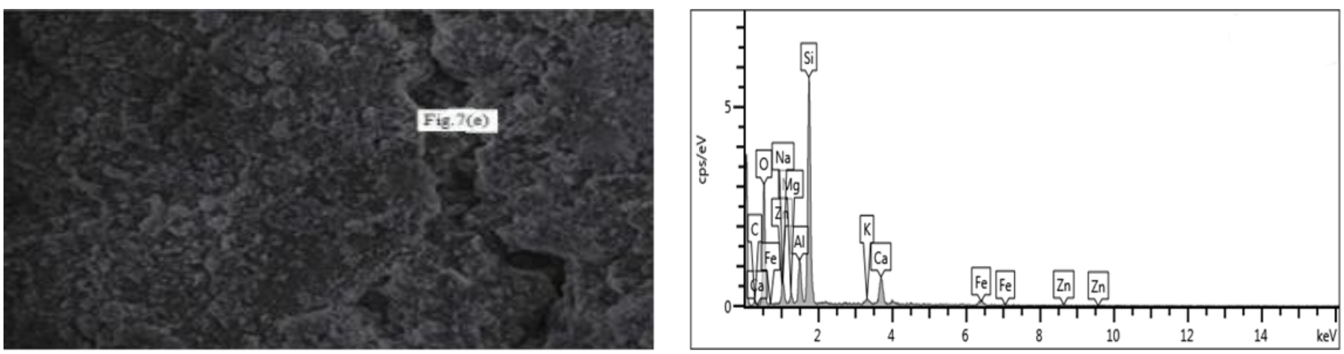
(b) SEM-EDS diagram of composite particles adsorbed Fe^{2+}



(c) SEM-EDS diagram of composite particles adsorbed Mn^{2+}



(d) SEM-EDS diagram of composite particles adsorbed Cu^{2+}



(e) SEM-EDS diagram of composite particles adsorbed Zn^{2+}

Figure 7. SEM-EDS spectra of composite particles before and after adsorption

comeposit particles disposed heavy metal ions of acid mine drainage. The optimum conditions for adsorbing heavy metal ions by bentonite-steel slag composite adsorbent are the optimal dosage of the composite adsorbent of 21 g/L, the shaking rate of 120 r/min, temperature of 25℃, adsorption time of 100 minutes and the initial wastewater pH7.

(2) When the four heavy metal ions existed independently in the simulated mine wastewater and the highest concentrations of Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} was 150 mg/L, 100 mg/L, 170 mg/L and 140 mg/L, respectively, the removal adsorption rate was 93.42%, 92.64%, 93.86% and 95.17%, respectively.

(3) SEM-EDS spectra show that the contents of Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} increased on the surface of composite particles. The results indicate that the composite adsorbent has a good effect on the removal of heavy metal ions from wastewater under the optimum reaction conditions.

Acknowledgement

This research project is made possible through the financial support from the National Natural Science Foundation of China (51474122, 51174267), the Hundred-Thousand-Ten Thousands Talents Program of Liaoning province (2014921069), and the China Environmental Protection Foundation (2014-123-2-14).

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