Efficient Iron Sequestration from Industrial Wastewater using Iron Oxide Magnetic Nanoparticles

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ABSTRACT: Metal sheets fabricator companies produced high content of metal ions especially iron in their wastewater that give a problem in the wastewater treatment. Conventional oxidation and precipitation method to remove the iron in the wastewater were not efficient since the effluent has more than the discharge standard allowed by the Department of Environment (DOE) and increased the sludge volume. Therefore, this study adopted magnetic nanoparticles (MNP) as an agent to sequestrate the iron and reduce the sludge volume in the industrial wastewater. The goal is to synthesize MNP with coating agents for iron removal and then be separated from the water by magnetic decantation. The MNP was synthesized using co-precipitation method at 70 °C with a different coating agent, namely polyvinyl-alcohol (PVA), polyethylene-glycol (PEG) and cetyl-ammonium bromide (CTAB). The removal efficiency of the modified MNP was studied by observing the surface morphology and the amount of iron removed in the wastewater at time interval. All samples were sent for characterization. All different samples of synthesized MNP were well crystallized with particle sizes in the range of 5nm to 100nm. The result showed the maximum iron removal of 90% at 100 minutes demonstrated by CTAB coated MNP. As a conclusion, this study provides an insight into the efficacy of the enhanced surface morphology of MNP by surfactant to remove metal ions, particularly iron in industrial wastewater.

Keywords: *Iron removal; coating agent; magnetic nanoparticles*

1. INTRODUCTION

Wastewater discharges from manufacturing companies and urban sources are significant contributors to a wide range of water contamination issues [1]. Many industrial wastewater effluents are contaminated with heavy metals that pose substantial environmental problems, including those from metal finishing and electroplating processes, mining extraction activities, textile firms, and nuclear power stations. To avoid the adverse impact of heavy metal pollutants in wastewater, efficient treatment before discharge to the receiving water stream is very important. There are many wastewater treatment methods; however, it is always a problem to select the most efficient process and economically viable solution. The problem arises when the disposal of sludge, the chemical dosage required and maintenance of mechanical equipment eventually increase the operating costs [2].

Traditional heavy metal removal procedures, especially chemical precipitation, have a significant drawback in the form of hazardous end sludge. The presence of heavy metal sludge necessitates further treatment, which will increase the industry's costs [3]. The use of magnetic iron oxide-based nanomaterials to remove heavy metals from wastewater is a more attractive option because it reduces the expense of operation in terms of chemical dose and sludge abundance. Furthermore, the use of nanoparticle technology in the increased demand for clean water may not only lessen the economic burden, but the research findings may also be potentially useful for other wastewater treatment challenges. At the end of the findings, the most efficient elimination of total iron content in industrial wastewater is identified with the best surface-engineered MNP.

The aim of the study was to investigate the possibility of modified surface MNP using various surfactants to sequestrate iron from industrial wastewater.

2. MATERIALS AND METHODS

2.1 *Materials*

The chemicals that were used in this experiment were iron(III) chloride hexahydrate (FeCl3.6H2O), Iron(II) sulfate heptahydrate (FeSO4.7H2O), Polyvinyl alcohol (PVA), Polyethylene Glycol (PEG), Cetylammonium bromide (CTAB), Sodium Hydroxide (NaOH) and Nitrogen (N2). All of these chemicals were bought from Sigma-Aldrich.

2.2 *Wastewater characterization*

The characterization was carried out by sending the wastewater sample to the Central Lab, Universiti Malaysia Pahang to measure the total iron content per litre volume. The result detected a very high iron concentration in the industrial wastewater which is 845.8 ppm and thus violates the standards proposed by Environmental Quality (Industrial Effluent) Regulations 2009 (EQA 2009). The source of the wastewater is taken from Cenviro Sdn Bhd which is a schedule waste handler in Port Dickson, Negeri Sembilan, Malaysia.

2.3 Co-precipitation of iron oxide

Magnetic nanoparticles (MNP) iron oxide nanoparticles were produced via the coprecipitation method as described in the previous work [4] with a little adaptation. A mixture of 25 millimoles of ferrous sulfate (FeSO4.7H2O) and 50 millimoles of ferric chloride (FeC13.6H2O) was dissolved in 100 ml of distilled water with the proper amount of surfactants (0.1%) of CTAB, PVA, or PEG. The mixture was stirred at 70°C for 1 hour under the inert atmosphere to ensure complete displacement of oxygen throughout the experiment. Then, 125 ml of deoxygenated NaOH (0.5 M) was added dropwise to the mixture. The mixture was stirred for 1 hour at 70°C to obtain the precipitate of MNP. Segregation of solid MNP was done by using a magnetic drive followed by washing it 5 times with distilled water to get rid of residual on its surface. The recovered MNP were dried overnight in an oven at 60°C and were gently crushed. The MNP was stored in an airtight tube (centrifuge tube) at room temperature for further use. The MNP synthesized without the surfactant was treated as the control.

3. RESULTS AND DISCUSSION

3.1 Metal iron removal

In this study, the adsorption activity of iron ions using magnetic nanoparticles (MNP) was observed from 20 minutes until 100 minutes of treatment time. The different coating agent of MNP influences the adsorption of the iron ion on the solid surfaces through the protonation and deprotonation of adsorbent surface functional groups [20]. This experiment has been carried out to detect the best coating agent on the adsorption of Fe ions onto magnetite nanoparticles. The percentage of iron removal trend was plotted as shown in Figure 1. The maximum percentage removal is 89.68%, 66.69%, 23.47%, and 9.7% for CTAB-MNP, PEG-MNP, PVA-MNP, and naked MNP respectively. It is observed that the removal of iron ions for all coated MNP increased as the time taken increase. This is expected because the longer the time taken for the water treatment, the more metal ions can be absorbed by the nanoparticles before it becomes saturated due to the gradual decrease of active binding sites [21].

The formation of hemimicelles by the alteration of the MNP surface with CTAB is responsible for the increased adsorption of Fe ions to the MNP. Both hydrophobic interactions and electrostatic attraction facilitate the desorption activity in hemimicelles, which are composed of a monolayer of CTAB transplanted on the surface of the MNP [22]. Interestingly, the highest and the second-highest iron removal was performed by CTAB-MNP and PEG-MNP which exhibit better particle dispersion and less agglomeration on their nanoscale image as seen in Figure 1b and Figure 1c. This is due to the fact that reduced dispersion tends to lower surface energy, hence decreasing MNP surface adsorption activity [23]. On the other hand, PVA-MNP shows a slightly lower percentage removal of 23.47% compared to the PEG-MNP and CTAB-MNP. PVA contains acetate groups which responsible for the negative charge of the polymer layer on the nanoparticle surface [24] unlike positively charged CTAB [25]. From these observations, the removal of Fe ion in this experiment seems to be assisted better in a positively charged MNP which can be developed by some coating agent.

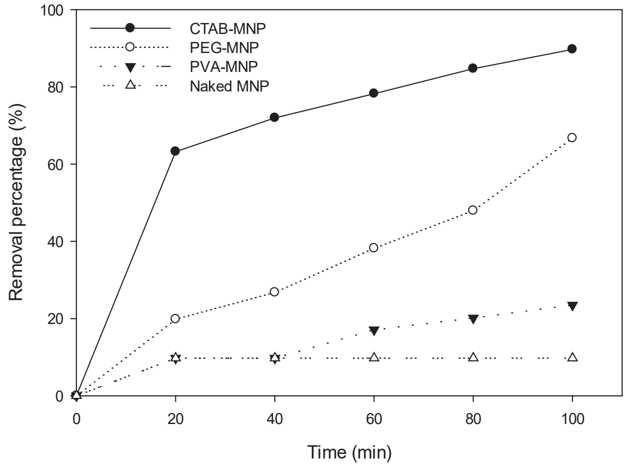

Figure 1 Percentage of iron removal (%) at different time after treated with naked MNP, CTAB, PEG and PVA coated MNP

These observations confirming the effect of surfactant where it enhances the surface area and the unique chemical interaction between the nanoparticles and the iron ions in the solution.

3. CONCLUSION

Overall, the concentration of iron (Fe) ions in industrial wastewater has been successfully treated due to their affinity towards the engineered surface of the synthesised MNP and the maximum of 89.68%% removal was achieved by CTAB-MNP. For future studies, it is recommended to extend the time taken for water treatments to get the maximum absorption of each MNP.

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