Development of Fe-Based Nanocomposites for Water Treatment and Methane Generation

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Title

（水処理とメタン生成のための Fe ベースのナノコンポジットの開発）

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論　文　内　容　の　要　旨

Thesis Summary

Nowadays, the world is suffering from increasing and exacerbating several environmental issues such as water consumption, water pollution, and waste generation. The world attests a significant consumption of clean water sources. Globally, the utilization of water supplies is doubled every 15 years because of the population growth. Along with increasing the consumption of clean water, water pollution is increasing all over the world due to the increased population and industrial activities, contributing to decrease the availability of clean water for human beings. Indeed, various pollutants already reached water supplies in many areas in different countries, including organic and inorganic pollutants. For these reasons, human societies are threatened by the risk of water pollution and the massive decrease in the available clean water. The World Health Organization (WHO) has declared that over than 40% of the world population use rare water resources. Thus, more than two billion people have no enough pure water access. Specifically, over 780 million people suffer in finding clean drinking water sources. Nitrate and phosphorus are the most discharged contaminants to water bodies and are known as nutrient pollution. They come from animal waste, industrial process, septic systems, and agricultural runoff. The contamination of water bodies by these contaminants causes several human health issues and environmental problems. For the environmental problems, the high release of phosphorus and nitrogen causes harmful effects of eutrophication. The oxygen depletion, biodiversity reduction, lower light transmission and generation of algal blooms occur in the lakes and rivers when the concentration of phosphorus exceeds 0.02 mg/L at which eutrophication starts. Regarding human health issues, nitrate contamination converts into nitrite, which in turn causes many diseases such as blue baby syndrome, liver damage, and cancer. Therefore, it has become an urgent need to treat contaminated waters such as household and industrial wastewater to compensate for the lack of clean water sources. Interestingly, due to the high content of organic matter in the household wastewater, treatment of wastewater could provide a renewable source of energy by integrating the anaerobic digestion process to the treatment system. Converting the organic matters to methane gas through anaerobic digestion during the treatment process generates energy which will be a solution for the depletion of nonrenewable sources of energy. However, the low conversion rate of organic matter to methane by anaerobes is the main challenge that affects the performance of the anaerobic digestion process. Therefore, the main target of this dissertation is to treat the polluted water along with accelerating the production of biofuels as a renewable source of energy to maintain the environmental sustainability and human societies. To achieve this goal, nanotechnology in the form of nanoparticles was used to remove the harmful pollutants from water and increase the production of methane gas from wastewater. Nanoscale zerovalent iron (Fe^0) has been proved to be one of the effective materials for water treatment and environmental applications. However, Fe^0 particles tend to aggregate rapidly due to their magnetic properties. The aggregation of Fe^0 particles decreases their efficiency when they used to treat the contaminated water. Therefore, the current thesis amid to improve the reactivity, physiochemical properties, and reaction mechanisms of Fe^0 particles for various environmental applications, including water treatment and energy/methane generation. To do so, the plan has been drawn to achieve the following goals of the dissertation. Firstly, it has been schemed to investigate the effect of various surfactants on the enhancement of Fe^0 reaction mechanisms. The target was to screen several surfactant to improve the reactivity of Fe^0 regarding two main mechanisms, including reduction and adsorption mechanisms, which are very common mechanisms to remove a wide verity of contaminants from water. Nitrate and phosphate were selected as a targeted contaminants to represent the reduction and adsorption mechanisms, respectively. Secondly, the plan included to use Fe^0 nanoparticles in the anaerobic digesters to improve the production of methane gas from waste sludge, which was used as a feedstock. To achieve this goal, the fresh Fe^0 particles were subject to the coating process using the thermal deposition method. The coating process was conducted to control/slow the corrosion reaction of Fe^0 particles and make them suitable additives in the anaerobic digesters. $Mg(OH)_2$ was used to coat the bare/Fe^0 particles due to its outstanding role in this process. Thirdly, this dissertation has included a plan to design a sequencing batch reactor system to be automatically operated to treat the contaminated wastewater alongside with converting the waste sludge to aerobic granules, which will further be used to remove organic/inorganic pollutants from water. The above points are general explanations for three projects which have been implemented in this thesis.

This thesis has a framework consist of six chapters that have been implemented to achieve the above-mentioned objectives.

Chapter 1 presents information concerning water pollution problems followed by an overview on the use of nanotechnology as a promising track of science to solve such problems. Also, this chapter covers the fabrications methods of Fe^0 particles, potential use of Fe^0 nanoparticles in environmental remediation, limitation of Fe^0 application and the modification of Fe^0 particles. Finally, the chapter showed the objectives and the frameworks of the current thesis.

Chapter 2 presents the methodology of the implemented works including reagents, protocols, procedures, material characterization, operation of the treatment systems, measurements of bacterial growth, and synthesis procedures of iron-based nanoparticles.

Chapter 3 presents the effect of polymeric stabilization on the reactivity of Fe^0 particles against nitrate and phosphorus removal from water. In this regard, four different polymers, including anionic and non-ionic polymers) were used to overcome the drawbacks of Fe^0 particles to efficiently remove nitrate and phosphorus from contaminated waters.

Chapter 4 presents a new technique used in this research to increase the production rate of methane gas. The new approach includes the use of Fe^0 coated with $Mg(OH)_2$ as an additive to improve the anaerobic digestion process of waste sludge. The experiments were performed in a batch mode and then scaled up to a semi-continuous system. The results of these experiments showed the great performance of the coated Fe^0 in improving methane production.

Chapter 5 presents an introduction about aerobic granulation technology as a new approach that can be used to convert the waste sludge to aerobic granules. And the limitation of this technology as it requires long time for full granulation. Also, the chapter showed the operation process of the sequencing batch reactor system and the methodology used in the work. Finally, the chapter presented the role of Fe^0 particles in accelerating the formation of aerobic granules and contaminants removal from wastewater using a sequencing batch reactor system (SBRS).

Finally, Chapter 6 presents the significant findings obtained from three projects on water treatment and energy generation with providing valuable recommendations for future research investigation. Additionally, the chapter displays the future research plan, expected results, and impacts.