

行政院國家科學委員會專題研究計畫 成果報告

奈米 FeO/CO₂ 程序串聯流體化砂濾床處理硝酸鹽污染用水 與回收氧化鐵覆膜石英砂之砷去除利用性評估 研究成果報告(精簡版)

計畫類別：個別型
計畫編號：NSC 98-2221-E-041-005-
執行期間：98年08月01日至99年07月31日
執行單位：嘉南藥理科技大學職業安全衛生系

計畫主持人：許嘉衿
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報告附件：出席國際會議研究心得報告及發表論文

處理方式：本計畫可公開查詢

中華民國 99 年 10 月 18 日

行政院國家科學委員會補助專題研究計畫 成果報告
 期中進度報告

奈米Fe⁰/CO₂程序串聯流體化砂濾床處理硝酸鹽污染用水
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成果報告類型(依經費核定清單規定繳交)： 精簡報告 完整報告

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中 華 民 國 99 年 10 月 18 日

出席國際學術會議發表之論文

The 8th Asian-Pacific Regional Conference on Practical Environmental Technologies (APRC2010)
Ubon Ratchathani University, Ubonratchathani, Thailand, March 24-27, 2010.

NITRATE REMOVAL BY SYNTHETIC NANOSCALE ZERO-VALENT IRON

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NSC 98-2221-E-041 -005

中文摘要

本研究之主要目的，在探討一內置4.3L反應溶液之內循環式反應槽中，合成奈米鐵對硝酸鹽之去除效率。實驗結果顯示，以3.3與6.6 mL min⁻¹幫浦蠕動流率混合奈米鐵合成試劑，其對硝酸鹽之去除效率相近，因此，本研究乃以固定奈米鐵合成條件為6.6 mL min⁻¹之方式完成本研究所有試驗。而於50 mL min⁻¹之氮氣曝氣條件下，所營造出之厭氧情況與初始pH=6.4之近中性環境中，可得70%之硝酸鹽去除率；其與CO₂曝氣，初始pH=4.0時所得5%之硝酸鹽去除率相較明顯高出許多。而為再度證實pH值對硝酸鹽去除效率之影響，本研究中又進行了一組以H₂SO₄與NaOH調整溶液pH值之試驗，結果發現，當pH值介於6-8時，可得80-84%之硝酸鹽去除率；由此結果可見，於此奈米Fe⁰/CO₂程序之反應系統中，CO₂曝氣所產生之碳酸根離子對硝酸鹽之去除為一抑制因子。此外，於硝酸鹽質量平衡反應中可發現，當溶液之初始pH=10時，所產生之最終產物多為氨氣，但當溶液之初始pH=6與8時，除了亞硝酸鹽與氮氣之形成外，發現尚有少部分含氮物質產生(可能以氮氣形式釋出)。由上述結果可知，對本實驗室合成之奈米零價鐵而言，控制反應系統之pH值使接近於中性為一有利於硝酸鹽去除之操作條件。

關鍵詞：硝酸鹽去除、奈米零價鐵、二氧化碳

NITRATE REMOVAL BY SYNTHETIC NANOSCALE ZERO-VALENT IRON

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NSC 98-2221-E-041 -005

ABSTRACT

The object of this study was to investigate the capability of nitrate removal by nanoscale zero-valent iron (nZVI) particles in a re-circulated flow reactor of 4.3 L liquid volume. In view of nanoparticle synthesis, nitrate removal by nZVI synthesized with different rates of reactants mixing (3.3 and 6.6 mL min⁻¹), was close to each other. Nitrate removal of 70% was observed with the initial pH of 6.4 and the solution being pre-purged by N₂ gas (anoxic condition) at a rate of 50 mL min⁻¹. However, when the solution was bubbled with CO₂ (anoxic condition), the nitrate removal efficiency was less than 5% with the initial pH of 4.0. As the pH was adjusted by H₂SO₄ and NaOH to the range of 6-8, nitrate removal efficiency of 80-84% could be attained. Such results demonstrate that carbonic acid generated from CO₂ bubbling may play strongly an inhibiting role as the aqueous nitrate was removed by the nZVI. In addition, based on nitrate mass balance, the end product was mostly dominated by ammonium at the initial pH 10. For the lower initial pH such as 6 and 8, some other nitrogen-contained species have been form in the reaction in addition to nitrite and ammonium.

Keywords: Nitrate removal, Nanoscale zero-valent iron (nZVI), CO₂

INTRODUCTION

High nitrate levels found in drinking water have been proven to be the cause for numerous adverse health effects across the world, including methemoglobinemia, stomach cancer and others [1]. Hence, a maximum nitrate concentration of 44 mgL⁻¹ (~10 mg NL⁻¹) by USEPA recommendation was applied as a safe drinking water quality standard in most developed countries [2].

At the present time, the techniques of biodenitrification [3], ion exchange, reverse osmosis [4], distillation and chemical reduction [5] were suggested to eliminate the nitrate contamination from water. Of these methods, biological denitrification processes are difficult to apply to inorganic wastewater treatment because of additional organic compounds of hydrogen donors required [6]. The ion exchange process is sensitive to waters containing high total dissolved solids, high sulfate, and high hardness levels, which can result in precipitation during regeneration. In addition, the drawback of this method is, as the resin exchange sites are filled with nitrate completely, nitrate breakthrough can occur.

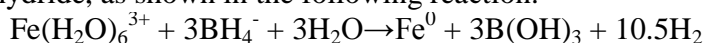
The reverse osmosis treatment has its limit since they are relatively expensive and merely transfer nitrate into concentrated waste brine that may pose a disposal problem [7]. Distillation works through the evaporation of water. Yet, this type of treatment is not economical for whole-house drinking water. In view of these reasons above, the chemical reduction process of nanoscale zero-valent iron (nZVI), which is characterized with large surface areas (particle size <100 nm) and high surface reactivity, is a newly emerging environmental remediation technologies [8,9]. In recent years, laboratory research has reported nZVI is very effective in destroying a wide variety of common contaminants, such as oxo-anions (e.g., nitrate, chromate) [10-14], halogenated organic compounds [15], heavy metals, and pesticides and dyes [16]. However, Huang and Zhang [9] have indicated that the feasibility of nZVI for nitrate removal depends on solution pH which, in terms of H⁺, may serve the roles such as (1) involving directly in the nitrate reduction; (2) affecting the nitrate adsorption onto reactive sites of iron surface, and (3) determining the formation rates and the compositions of the oxide layers.

Thus, this study attempted to remove nitrate by nZVI synthesized in the laboratory. Specifically, system parameters such as nZVI of different preparation conditions, solution pH, and initial nitrate concentrations were investigated.

MATERIALS AND METHODS

Wastewater Characteristics

In this study, the working solutions of nitrate, iron(III) chloride, and borohydride were prepared in the laboratory by dissolving predetermined amount of KNO₃, FeCl₃ · 6H₂O, and NaBH₄ in the deionized water of 18.2MΩ cm⁻¹. A nitrate concentration of 100 mgL⁻¹ (~22.5 mg-NL⁻¹) prepared from sodium nitrate (Merck KGaA Germany) was used in this study. Nanoscale Fe⁰ particles used in this study were prepared by modifying the method by Glavee et al. (1995) [17]. With 1:1 volume ratio, the NaBH₄ (0.25 M) was pumped into FeCl₃ · 6H₂O (0.045 M) solution by peristaltic pump at room temperature, and the mixture was mixed by a revolving propeller. The ferric ion was reduced by the reducing agents of borohydride, as shown in the following reaction:



The electrons were released from NaBH₄ and further transferred to ferric ion. After the mixture was stirred for 2 min, the nZVI particles were separated from liquid solution by a magnet. Afterwards, the nZVI was thus-produced and readily available for use without any further treatment.

Reactor Setup

The experiments were conducted in a cylindrical reactor of 5 L. The liquid volume was 4.3 L. Because the iron particles show a strong tendency to aggregate, much effort has been directed towards methods to disperse the particles in water, rendering them mobile. In this study, internal re-circulated flow was used to achieve homogeneous mixing of solution using a peristaltic pump. The CO₂ gas was introduced by passing through a disk diffuser of silicate material installed at the bottom of the reactor. As the experiments were completed, water samples were taken from the reactor at different time intervals for subsequent analyses.

RESULTS AND DISCUSSION

Nitrate removal by nZVI synthesized with different pumping rates

To prevent the oxidation of nZVI in the synthesis process, two pumping rates of NaBH_4 , 3.3 and 6.6 mL min^{-1} , were used to prepare the nanoscale particles. Figure 1 presents the nitrate removal capacity for nZVI prepared at the different pumping rates. Results show that nitrate removal performance was of no difference the above two types of nZVI in the first hour of reaction. To be consistent and speedy, the pumping rate of nZVI was set at 6.6 mL min^{-1} for all experiments in this study.

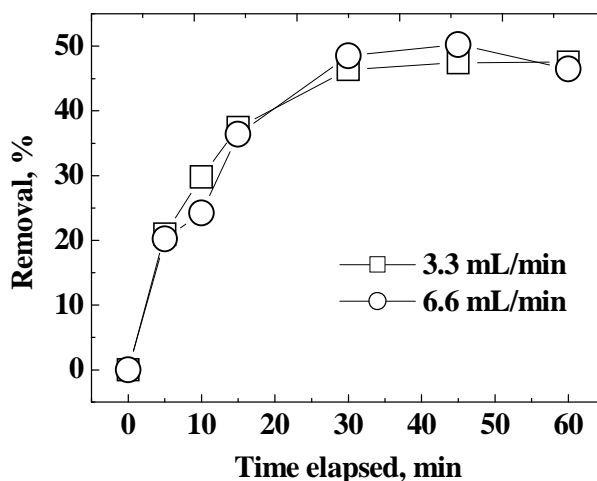


Figure 1. Nitrate removal efficiency with nZVI synthesized at various pumping rates of NaBH_4 for mixing (anoxic condition, initial nitrate = 100 mgL^{-1} , Fe^0 dosage = 0.25 g)

Characteristics of nZVI synthesized

Through the TEM analysis, Figure. 2 shows that the average diameter of nZVI ranges from 50 to 60 nm, with an average size of 56 nm, and its specific surface area was $7.67 \text{ m}^2\text{g}^{-1}$. As illustrated by the TEM image, the nZVI tends to form a chainlike aggregate due to the electrostatic force between particles. These chain-like nano iron aggregates were also observed by some other researchers [18-20]. This result suggests that the particles are easily aggregated and do not exist in individual forms due to spontaneous aggregation of nanoparticles [21]. Moreover, surface morphology shows that there exists two layers in the nZVI particle. The layer of inside core represents the Fe^0 , and the outer layer surrounding on the Fe^0 was iron-oxide(s).

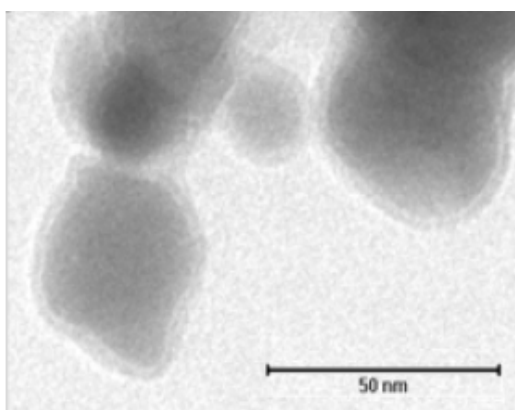
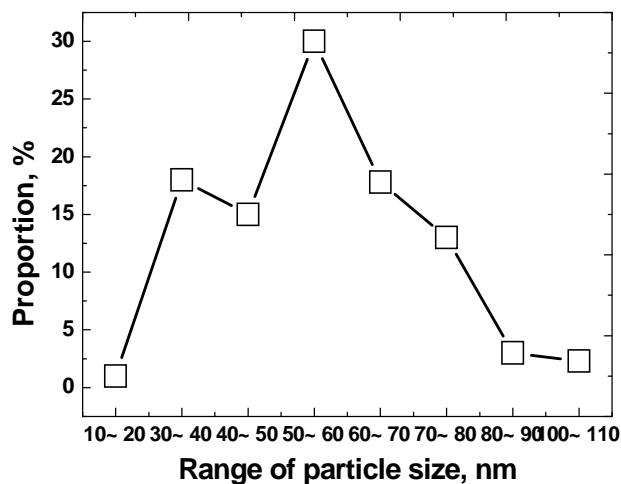


Figure 2. Particle size distribution and TEM image of nanoscale iron particle

Effect of initial nitrate concentration

The effect of initial nitrate concentration on nitrate removal was carried out by using three different nitrate concentrations and four step additions of nZVI of 0.25 g. As shown in Figure 3, the nitrate residue was reduced almost completely within 4 h for the initial nitrate of 50 mgL⁻¹. In contrast, the removal efficiencies of 75% and 42% were obtained, given the initial nitrate of 100 and 200 mgL⁻¹, respectively. It appears that the normalized residual nitrate concentration decreases with increasing nitrate concentration.

According to the literature, both water and nitrate molecules will compete with each other for Fe⁰-released electrons, leading to the formation of ferrous ions [22]. However, no detectable amount of ferrous ion was observed over the reaction period. Such result implies that the initial nitrate concentration is sufficiently high that Reaction (1) occurs much faster than Reaction (2). In addition, it is also implied that the Fe⁰ corrosion rate is accelerated, depending on the concentration level of nitrate in the solution.

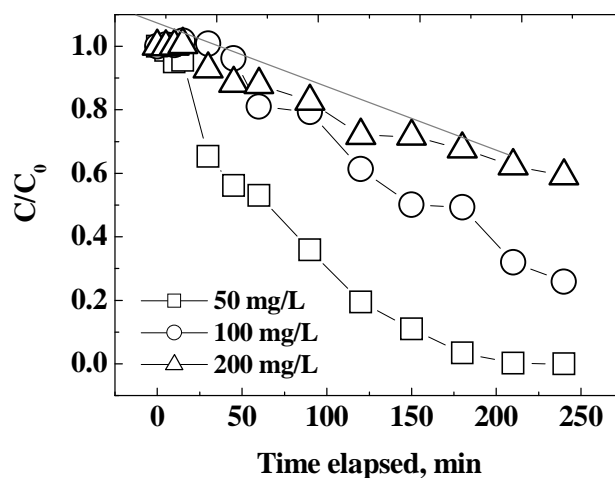
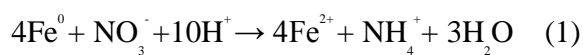


Figure 3. Effect of initial nitrate concentration on nitrate reduction: anoxic condition, initial nitrate concentration = 50, 100, 200 mg L⁻¹, Fe⁰ dosage: four step additions of nZVI of 0.25 g, liquid volume = 4.3 L)

Effect of pH on Nitrate Removal

Experiments of nitrate reduction by nZVI under the conditions of CO₂ and N₂ pre-purging at a rate of 50 mL min⁻¹ were conducted; the solution pH's resulted from these two purging were 4 and 6.4, respectively. As illustrated in Figure 4(a), the nitrate removal of 70% could be attained when N₂ was pre-purged. Whereas the nitrate removal seemed to be inactivated as the CO₂ gas was applied to remove dissolved oxygen as well as to acidify the solution. As might be expected, the bubbling of CO₂ into water to supply hydrogen ions is favorable for nitrate removal. But, the result appears to indicate that carbonic acid may play strongly an inhibiting role, as the aqueous nitrate is removed by the nZVI synthesized in this study.

Additionally, oxygen can act as a role of electron acceptor similar to the nitrate in the Fe⁰ system, leading to the inhibition of nitrate removal. The results show that removal efficiency of nitrate could be improved better by N₂ pre-purging of dissolved oxygen than by CO₂ bubbling into the solution. A test of pH effect was further conducted to confirm such phenomenon in the absence of oxygen, i.e., anoxic condition. With the use of H₂SO₄ and/or NaOH for solution pH adjustment, Figure 4(b) presents nitrate removal profiles under different pH values as well as negligible amount of dissolved oxygen. Results show that with the pH's at 6, 8, and 10, the efficiencies of nitrate removal reaches around 80-84% in 5 h, and it was only 14% with the pH at 4. The results indicate that the solution pH must be maintained at around the neutral range to create a favorable pH condition for nZVI reduction of nitrate. Such results agree with the literature report in regard to the role of pH in the nitrate reduction [23].

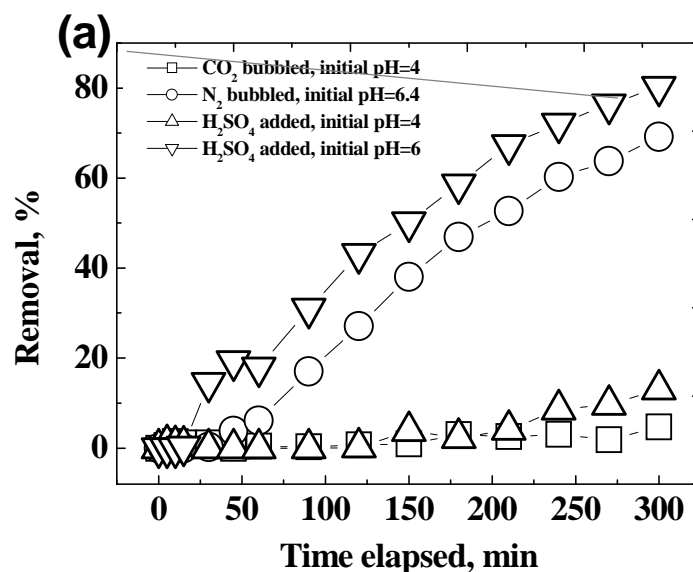


Figure 4(a). Effect of pH on nitrate removal with pH controlled by CO₂ bubbling and H₂SO₄ addition. Initial nitrate = 100 mgL⁻¹, Fe⁰ dosage: four step additions of nZVI of 0.25 g, gas inflow rate = 50 mL min⁻¹, liquid volume = 4.3 L

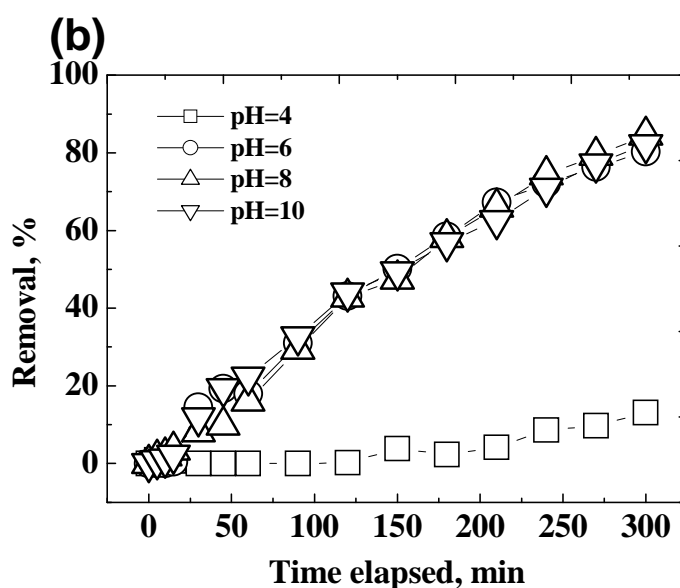
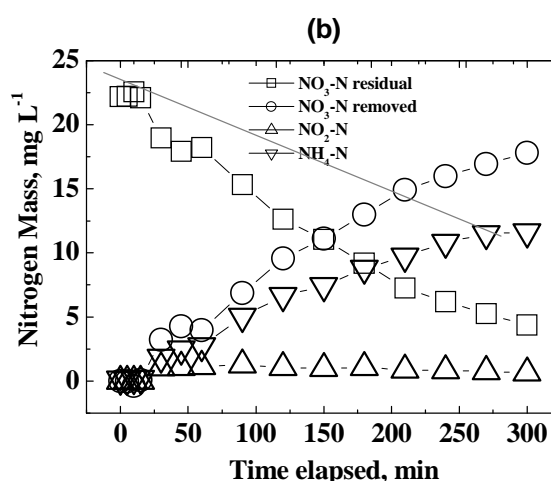
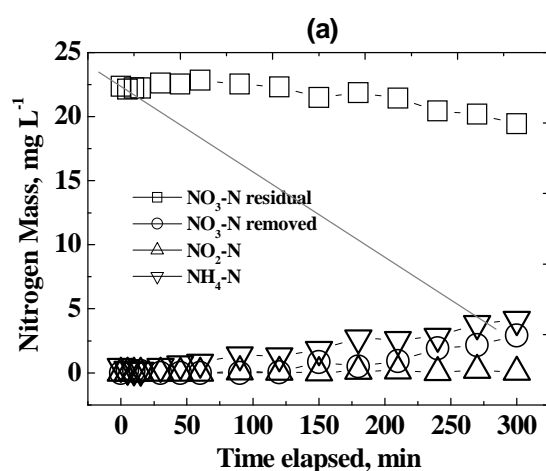


Figure 4(b). Effect of pH on nitrate removal with pH controlled by H₂SO₄ and/or NaOH addition. Anoxic condition, initial nitrate = 100 mgL⁻¹, Fe⁰ dosage: four step additions of nZVI of 0.25 g, liquid volume = 4.3 L

Intermediates of nitrate reduction

In regard to the pH effect on nitrate removal, Figure 5 shows the concentration profiles of nitrate, ammonium and nitrite as a function of time under various pH values. It appears that the end reduction products of nitrate were accounted for mostly by ammonium at pH 6, 8, and 10. However, the intermediate of nitrite under all pH conditions is negligible, which are less than 0.4 mg-NL^{-1} . Such results are in agreement with some other report [24, 25].

The conversion of nitrogen-containing species of this study is nearly 82% for the solution pH at 10, while it is around 48-55% at pH = 6 and pH = 8. This indicates that the conversion of nitrogen species decreases with decreasing pH. Hence, it was concluded that the solution pH needs to be controlled at neutral value to improve the nitrate removal performance by the nZVI synthesized in this study. However, formation of the undesirable end-product ammonium is the drawback for this nZVI method. The subsequent treatment of ammonium is required.



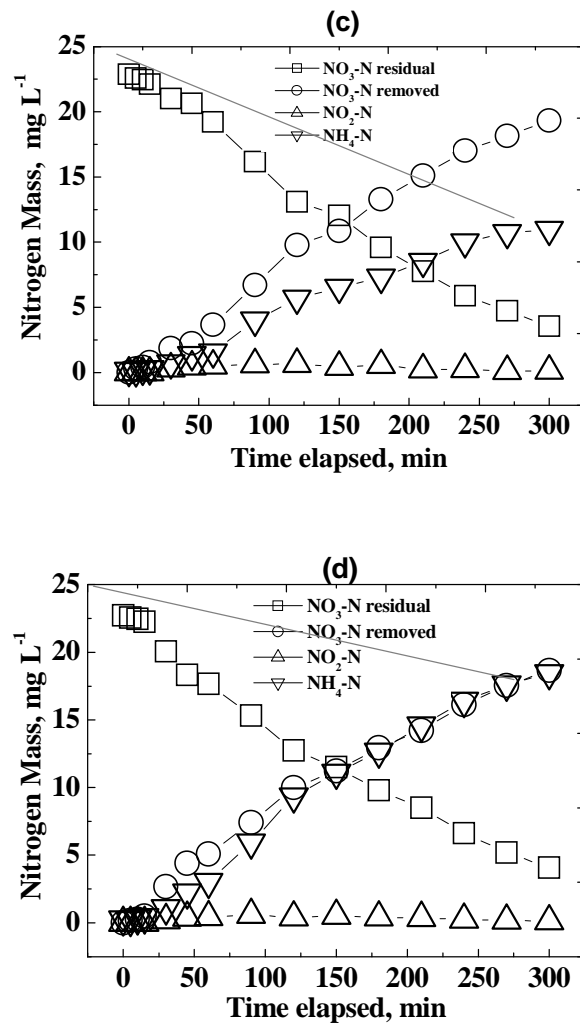


Figure 5. Intermediates of nitrate reduction with (a) the pH =4; (b) the pH = 6; (c) the pH = 8; (d) the pH =10. anoxic condition, initial nitrate = 50 mgL⁻¹, Fe⁰ dosage: four step additions of nZVI of 0.25 g, liquid volume = 4.3 L.

CONCLUSIONS

The method of nanoscale zero-valent iron particles was capable of removing nitrate of more than 80% in a re-circulated flow reactor in this study. In addition, it appears that carbonic acid formed by CO₂ bubbling plays a strong role in inhibiting the aqueous nitrate removal by the nZVI synthesized in this study. It is concluded that the solution pH needs to be controlled within the neutral range to improve the nitrate removal by the nZVI method. On the other hand, in view of the end-products of nitrate reduction, they were mainly dominated by ammonium at the higher pH value. Therefore, the neutral pH seems to be most favorable to avoid the undesired ammonium formation and, at the same time, to maximize the most removal of nitrate.

ACKNOWLEDGMENT

This research was sponsored by the National Science Council, Taiwan under project No. NSC 98-2221-E-041-005.

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本年度計畫成果自評

計畫名稱：奈米 Fe^0/CO_2 程序串聯流體化砂濾床處理硝酸鹽污染用水與回收氧化鐵覆膜石英砂之砷去除利用性評估

Practical evaluation of nitrate polluted water treatment by means of Nano Fe^0/CO_2 procedure combined with fluidized sand filter bed and evaluation of recycling iron-oxide coated sands in arsenic removal

(NSC 98-2221-E-041-005)

本研究內容與原計畫相符程度達 98%，已完成預期工作項目及成果簡述如下：

A. 已完成本研究奈米 Fe^0/CO_2 反應程序中，變化 pH 值、污染物濃度、奈米鐵劑量與不同曝氣條件(N_2 與 CO_2)對硝酸鹽去除效率之探討。所得結果如下：

- (1). 於 100 ppm 硝酸鹽溶液中，以預曝 N_2 再加奈米鐵方式進行，於 4 小時內僅需 0.23g/L 奈米鐵，即可達 70% 硝酸鹽去除率。
- (2). 本實驗室合成之 Fe^0 ，於 pH=6 與 pH=8 條件下，分別可得 82% 與 80% 之硝酸鹽去除率，建議中性偏鹼性條件為本研究較佳之硝酸鹽去除環境。
- (3). 於硝酸鹽質量平衡反應中，當溶液初始 pH=10 時，最終產物多為氮氣，但當溶液初始 pH=6 與 8 時，除亞硝酸鹽與氮氣形成外，尚發現部分含氮物產生(可能以氮氣形式釋出)。故對本實驗室合成之 Fe^0 ，控制反應系統之 pH 值使接近於中性為一有利於硝酸鹽去除之操作條件。

B. 已完成 Fe^0/CO_2 反應程序中，變化不同砷物種(As(III), As(V), As(III)+As(V))與砷濃度條件下，合成奈米鐵對砷去除效率之探討。所得結果如下：

當不同砷物種或總砷存在時，控制 pH 於 8.1-8.7 間，可得 99-90% 去除率，顯現於此系統中，偏鹼性亦為砷去除較佳環境。

C. 已完成 Fe^0/CO_2 反應程序中，硝酸鹽與砷併除效率之探討。所得結果如下：

於硝酸鹽與砷共存環境中，兩者間相互競爭與去除干擾情形並不顯著，顯見於此奈米 Fe^0/CO_2 程序中，併除水中硝酸鹽與砷為一可行技術。

D. 已完成 Fe^0/CO_2 反應程序串聯砂濾床中，曝空氣入砂濾床後石英砂表面氧化鐵覆膜情形之探討。但所得結果，若與先前本實驗室曾執行之微米鐵/ CO_2 反應相較，此部分所得結果為本研究中未如預期部分。原因為：奈米零價鐵在 CO_2 反應程序中，因溶液之最終 pH 均落於中性偏鹼性範圍，此將不利於 Fe^{2+} 之形成(且於此反應槽中均測不到 Fe^{2+} 濃度)，此為本計畫中未如預期部分。

國科會補助專題研究計畫項下出席國際學術會議心得報告

日期：99年9月18日

計畫編號	NSC 98-2221-E-041-005-		
計畫名稱	奈米 Fe ⁰ /CO ₂ 程序串聯流體化砂濾床處理硝酸鹽污染用水 與回收氧化鐵覆膜石英砂之砷去除利用性評估		
出國人員姓名	許嘉衿	服務機構及職稱	嘉南藥理科技大學 環境工程與科學系(所) 副教授
會議時間	99年3月24日至 99年3月27日	會議地點	泰國, 烏汶 Ubon Ratchathani, Thailand
會議名稱	(中文) 第八屆亞太地區環工應用技術研討會 (英文) The 8 th Asian-Pacific Regional Conference on Practical Environmental Technologies (APRC 2010)		
發表論文題目	(中文) 合成奈米零價鐵去除硝酸鹽之研究 (英文) NITRATE REMOVAL BY SYNTHETIC NANOSCALE ZERO-VALENT IRON		

一、參加會議經過

2010年邁入第八屆的亞太地區環工應用技術研討會(Asian-Pacific Regional Conference on Practical Environmental Technologies, APRC)，今年是由Ubon Ratchathani University所主辦，於泰國烏汶舉行，議程共為期二天。此一研討會係由泰國Ubon Ratchathani大學與其鄰近東南亞地區友好大學所輪流主辦，本年度共有泰國、越南、菲律賓、台灣等國家所屬環工類組各系(所)師生；與來自世界各地對水污染議題有興趣之相關學、業界學者參與此盛會，屬一東南亞地區大規模之環工相關議題研討會。此一研討會之所以能持續辦理，乃有鑑於開發中或第三世界國家經濟蕭條，於某些偏遠地區仍有多數家庭仰賴挖井取水，且僅經簡易砂濾過程即以之為飲用水源，故地下水污染議題更顯值得重視。因此，主辦單位每年希藉此研討會之舉行廣納各方學術意見，交換技術研發成果，以朝研討會重點目標：共同發展創新性與低成本水處理技術而邁進。

本人為國科會計畫新進人員，因博士班修業階段之研究多以水污染防治為主軸，故承蒙國科會經費補助下，今年得以有此機會前往泰國參加此學術研討會，並以壁報方式發表論文，題目為：“Nitrate removal by synthetic nanoscale zero-valent iron” (NSC 98-2221-E-041-005-)與“Arsenic removal by nano zero-valent iron: Effect of initial concentration and dissolved oxygen”。發表時間為99年3月24日上午9點至25日下午4點止。當天共有15篇poster發表之文章，過程中每位作者均會站在大型海報邊，供與會人士詢問疑惑並進行問題討論。且此研討會今年廣為提供不同session room，以作為不同領域學者發表“Water and wastewater”，“Solid and hazardous waste”，“Air pollution”，及“Health risk”等相關主題之場所。由於本人發表之主題著重於今年計劃核可部分，主要對實驗室合成之奈米零價鐵曝氣CO₂程序並串聯流體化砂濾床以處理硝酸鹽污染用水之效率進行評估，故亦會在適時時間內至“Water and wastewater” session room中聆聽水質處理等相關研究發表，以從中增長見聞並擴展日後研究構思。

此外，3月26-27兩日大會又為我們安排了一系列的學術參訪與環工相關技術交流行程，內容安排如下：

- 1.至烏汶 Ubon Ratchathani University 進行學術參訪與交流。
- 2.參訪泰國政府強力輔導外商進駐之「太陽能發電示範廠」。
- 3.參觀泰國集中全國垃圾量的垃圾掩埋場之運作情形。
- 4.至曼谷King Mongkuts University of Technology Thonburi (KMUTT University) 環境工程系進行學術參訪與交流，隨後賦歸。

於此次為期四天的研討會與考察參觀活動中，我們除攜回研討會論文集及論文光碟外，尚取得一些泰國推動太陽能發電之DM；與相關友好大學之學校開課與系上教師研究方向等寶貴資料，相信可為日後雙方的學術交流與交換學生提供更多研擬管道。因此對吾人而言，今年有機會參加此場學術盛會實讓我獲益良多。

無研發成果推廣資料

98 年度專題研究計畫研究成果彙整表

計畫主持人：許嘉祯		計畫編號：98-2221-E-041-005-				
計畫名稱：奈米 Fe ₀ /CO ₂ 程序串聯流體化砂濾床處理硝酸鹽污染用水與回收氧化鐵覆膜石英砂之砷去除利用性評估						
成果項目		量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
		實際已達成數（被接受或已發表）	預期總達成數（含實際已達成數）	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇
		研究報告/技術報告	0	0	100%	
		研討會論文	0	0	100%	
		專書	0	0	100%	
	專利	申請中件數	0	0	100%	件
		已獲得件數	0	0	100%	
	技術移轉	件數	0	0	100%	件
		權利金	0	0	100%	千元
	參與計畫人力（本國籍）	碩士生	2	0	100%	人次
		博士生	0	0	100%	
		博士後研究員	0	0	100%	
		專任助理	0	0	100%	
國外	論文著作	期刊論文	1	1	100%	篇
		研究報告/技術報告	0	0	100%	
		研討會論文	1	0	100%	
		專書	0	0	100%	章/本
	專利	申請中件數	0	0	100%	件
		已獲得件數	0	0	100%	
	技術移轉	件數	0	0	100%	件
		權利金	0	0	100%	千元
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次
		博士生	0	0	100%	
		博士後研究員	0	0	100%	
		專任助理	0	0	100%	

<p>其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)</p>	<p>無</p>
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	成果項目	量化	名稱或內容性質簡述
科 教 處 計 畫 加 填 項 目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與(閱聽)人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

達成目標

未達成目標（請說明，以 100 字為限）

實驗失敗

因故實驗中斷

其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文： 已發表 未發表之文稿 撰寫中 無

專利： 已獲得 申請中 無

技轉： 已技轉 洽談中 無

其他：（以 100 字為限）

已投稿至 'Journal of Environmental Engineering and Management' . 此刻正在答覆 Reviewer 的意見。

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以500字為限）

本提案之研究目標，主要是針對以挖井、手搖幫浦採取地下水，並經簡單砂濾方式處理之經濟蕭條第三世界國家提出一低成本與易操作，可直接使用於一般家庭與社區地下水之硝酸鹽與砷污染處理技術。本研究特點為：結合流體化床、零價鐵還原技術，除探討奈米 Fe₀/CO₂ 程序處理硝酸鹽污染用水之反應機制外，將同時了解串聯流體化砂濾床中石英砂表面氧化鐵之覆膜情形，此結果將有助於硝酸鹽降解機制之瞭解，以作為日後氮氣或氮氣去除系統設計重要參考資料，且提供了後續砷去除試驗所需材料。藉由本計畫之完成，除證實本系統為一可行新技術外

；並將為後續實驗提供如下助益：

(1). 反應系統硝酸鹽去除機制之瞭解：

除應證系統操作成效與收集日後處理現地地下水質所需系統運作資料外，於硝酸鹽去除過程中，其去除效率

與衍生因子(亞硝酸鹽、氮氣或氮氣)間質量平衡機制，與其他相關研究之異同點可獲充分了解；並可為後續

Fe₀/CO₂ 程序串聯氮氣去除系統之設計提供可用資訊。

(2). 系統併除硝酸鹽與砷可行性之了解

由本研究硝酸鹽與砷共存之反應系統中，可知兩者間之相互競爭情形並不顯著，由此可見，於此奈米 Fe₀/CO₂

程序中併除水中硝酸鹽與砷為一可行之新技術。