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Evaluation of iron-rich adsorbent to remove arsenic from groundwater in decentralised water supply treatment

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Abstract:

This paper evaluates the adsorption capacity of iron-rich adsorbent to remove arsenic from groundwater in decentralised water supply treatment; a pilot-scale with a capacity of 5 m^3/day has been investigated at Cu Da Nursery School in Hanoi city, in which the concentration of arsenic in groundwater is abnormally high (175-400 µg/l). The pilot system was designed to include a series of processes, such as aeration, sedimentation, sand filtration, and adsorption, using the iron-rich adsorbent and activated carbon from coconut shells. The pilot system was tested with three operated modes. The results demonstrate that the treatment efficiency of the overall treatment processes was significantly higher than that of the traditional treatment system used by local people. After aeration, sedimentation, and sand filtration, the water quality was discovered to respond substantially in reducing iron by over 96% (from 8-12 mg/l to less than 0.3 mg/l) arsenic by 55 to 60%, but after iron-rich adsorbent, the concentration of arsenic decreased to less than 10 µg/l, which fulfills Vietnam National technical regulations concerning drinking water quality.

Keywords: **adsorbent, arsenic, decentralised water supply groundwater.**

Classification number: **5.1**

Introduction

Groundwater is a water source used for living and drinking purposes. In Vietnam, arsenic concentrations in groundwater are exceptionally high in many areas. A broad survey of arsenic pollution in the 12 provinces of the Red River Delta, Central area, and Mekong Delta was conducted by the Vietnamese government with UNICEF funding in 2008. A total of 12,439 water samples were analysed with arsenic in 419 communes of 33 districts in these 12 provinces. Analytical results indicate that some provinces of the Red River Delta and Mekong Delta had tube well water in which arsenic concentrations significantly exceeded Vietnamese technical regulations (≤10 µg/l for drinking water and ≤50 µg/l for domestic water); 34.9% and 21.1% of tube wells had arsenic concentrations above 10 µg/l and 50 µg/l, respectively [1]. The concentration of arsenic in groundwater in the Red River Delta was between 1 and 3,050 µg/l (average 159 µg/l) [2]. An estimated 17 million Vietnamese may face the potential risk of arsenic poisoning from using groundwater [3].

Decentralised water treatment is an effective and appropriate solution for households or groups of households in rural and suburban areas in Vietnam. This may also be effective in areas where the central water supply treatment system is lacking, when re-pollution occurs in the pipeline system before reaching end users, or in emergency cases, such as flooding, epidemic disease, etc. [4]. A decentralised water supply system may be more cost-effective than a centralised system because the central conveyance, treatment capacity, and potable water transmission reduce costs [5]. In rural areas of Vietnam, groundwater has been pumped from drilled wells and treated through a simple filtering system that involves rock, sand, and activated carbon or used directly; this was unable to remove arsenic in water.

To provide safe drinking water, effective treatment technologies for removing arsenic from groundwater must be applied. However, the implementation of efficient water treatment technologies may require significant capital investment and high operating costs for households. In Vietnam, some low-cost technologies have been investigated in relation to their

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ability to adsorb arsenic through natural iron-rich or manganese-rich materials such as red mud, laterite, etc. This research has yielded positive results at the laboratory scale [6]. The results have demonstrated that the highly-efficient adsorbents were made from iron-rich materials. This paper aims to evaluate the potential to remove arsenic from groundwater using iron-rich adsorbents on a pilot scale, with a capacity of 5 m^3/day at Cu Da Nursery School in Hanoi, where arsenic concentrations in groundwater are abnormally high (175-400 µg/l).

Materials and methods

Iron-rich adsorbent preparation

The iron-rich material iron (III) hydroxide was prepared in the laboratory based on the reaction of $FeCl_3$ with NaOH. These materials were weighed and mixed based on the mixing ratio (% by weight) of 40% ferric hydroxide, 10% alumium hydroxide, 7.5% additive 1, 18.5% additive 2, and 24% kaolin. Two types of mineral soils (K soil and yellow clay soil), which are common and easy to find in Vietnam and are regarded as additives, were added to create porosity and adhesive. The mixed materials were molded into cylinders which were 10 mm in diameter and 10 to 15 mm in height. Cylinders were then dried at 50°C for 24 hours and burned at 500°C for 10 hours. Finally, iron-rich adsorbents were cooled naturally, and broken pellets were removed by sieves.

Pilot operation

The pilot-scale with a capacity of 5 m^3/day was developed at Cu Da Nursery School in Hanoi city, where the concentration of arsenic in groundwater is abnormally high (175-400 µg/l). The adsorbent columns with dimensions of 760x1,500 mm (diameter x height) were created, fixed with 300 mm-high sand; the height of iron-rich adsorbents varies with each mode (Fig. 1). The pilot system was tested with three operated modes: (i) without aeration and 120 mm of iron-rich adsorbents, (ii) with aeration and 120 mm of iron-rich adsorbents, and (iii) with aeration and 250 mm of iron-rich adsorbents.

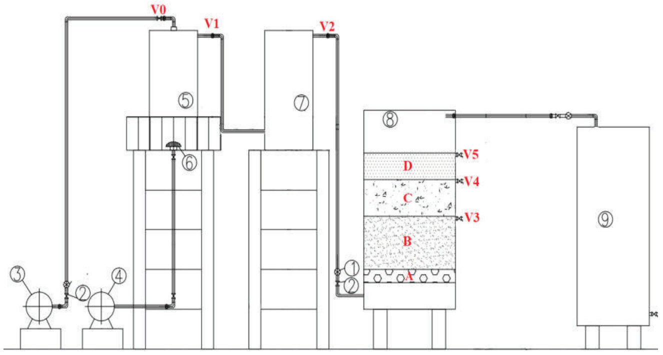


Fig. 1. Pilot system model in second and third modes

Note: 1 - flow meter, 2 - valve, 3 - pump, 4 - air blower, 5 - aeration tank, 6 - aeration tube, 7 - sedimentation tank, 8 - main treatment tank, 9 - bunker tank.

A - gravel layer, B - sand layer, C - iron-rich adsorbents, D - activated carbon layer.

pH was measured at the sampling site. The concentrations of iron and arsenic in water were analysed by AAS in the laboratory (AAnalyst 400, Perkin Elmer Inc).

Water samples were captured at V0 - groundwater, V1 - after aeration, V2 - after sedimentation, V3 - after sand filtration, V4 - after iron-rich adsorbents, and V5 - treated water (after activated carbon layer). All sampling locations have a suitable sampling valve.

Results and discussion

Effect of pH on changing operation mode

Figure 2 indicates the pH change in water after passing the pilot system. The results from Fig. 2 illustrate that, at the second and third modes, the pH of the treated water samples were slightly increased by the removal of iron of the pilot system, from 6.9 to 7.8.

In the second and third modes, after forced aeration, pH of the water increased slightly (from 6.5 to above 7) due to oxidation and precipitation of iron. pH of the water remained stable after sand filtration (V3) (between 7 and 7.5) and slightly increased when it passed the iron-rich adsorbents because of the alkalinity of kaolin in the iron-rich adsorbents. The increase pH values in the aeration and precipitation processes displayed the tendency of the oxidation of Fe (II) and As (III) to precipitate Fe (III) and soluble As (V). The ability to remove arsenic from water was facilitated significantly by this conversion since As (V) is adsorbed more efficiently by $Fe(OH)_3$ colloids than As (III).

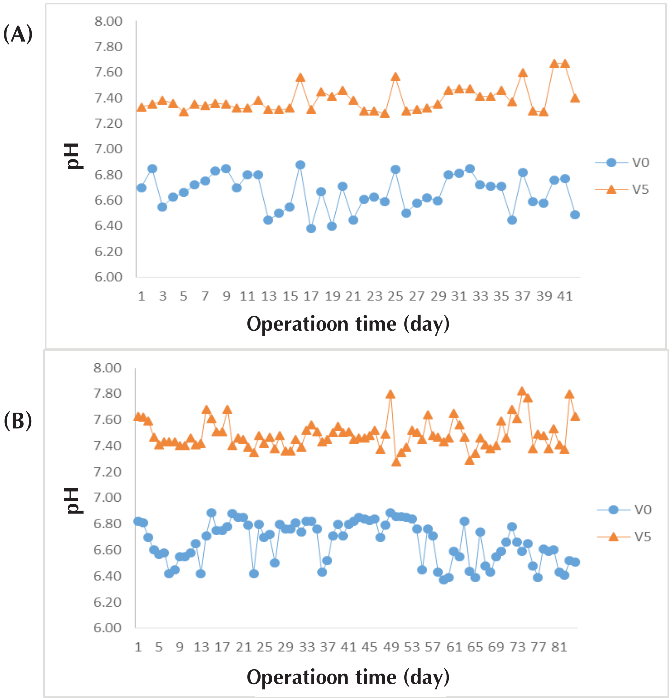
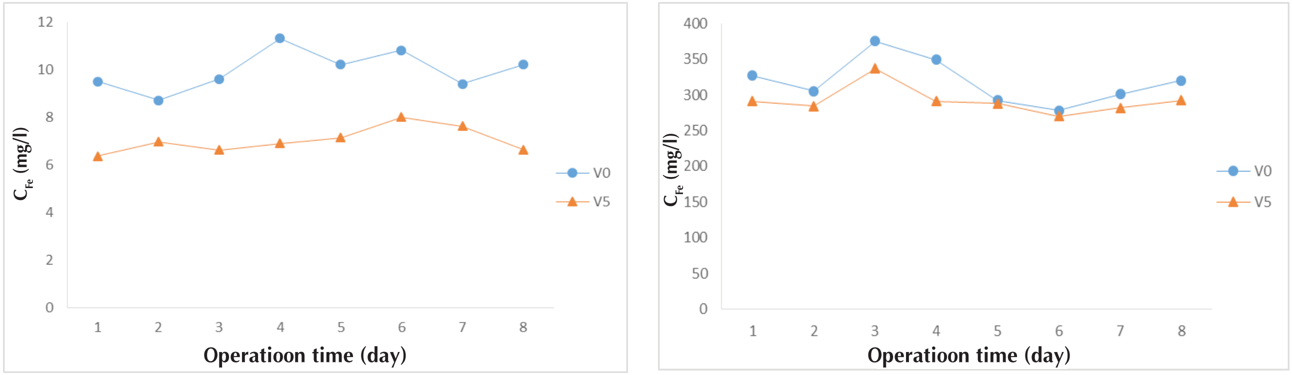


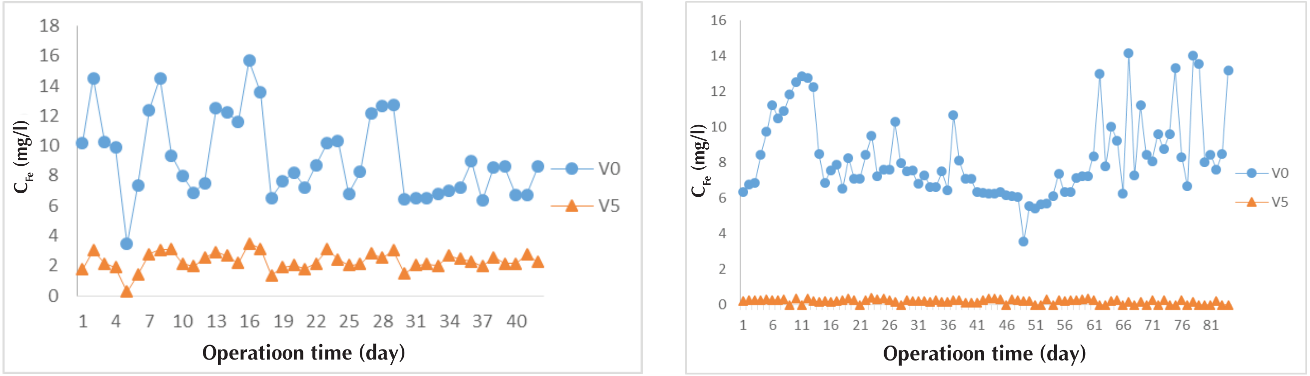
Fig. 2. pH of water samples in each mode. (A) The second mode and **(B)** the third mode.

Note: V0 - groundwater, V5 - treated water.



(A) **(B)**

Fig. 3. Removal of iron and asenic the first mode. (A) Removal of iron and (**B**) removal of arsenic.
Note: V0 - groundwater, V5 - treated water.



(A) **(B)**

Fig. 4. Removal of iron in the second and third operated mode. (A) The second operated mode; (**B**) the third operated mode.
Note: V0 - groundwater; V5 - treated water.

Effect of aeration process on the efficiency of the pilot system

Figure 3 illustrates the first mode with a capacity of 5 m^3/day, 120 mm-high iron-rich adsorbents, and the absence of aeration. The efficiency of removal of iron from groundwater was between 25 and 35%, whereas the treatment system was incapable of removing arsenic. The concentration of arsenic in V5 was insignificantly lower than that in V0.

In the second mode, the pilot system was installed with aeration. The adsorption column in the pilot scale achieved 76% removal of arsenic (ranged from 12 to 50 µg/l after overall treatment processes) and about 85 to 90% removal of iron from groundwater.

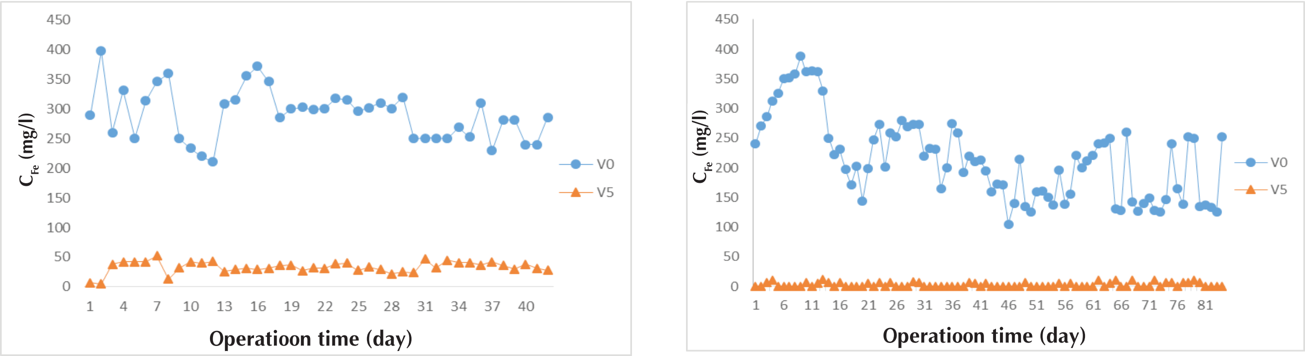
In the second mode, after sedimentation (V2), the concentration of arsenic decreased remarkably to 150 µg/l (approximately 50% relative to concentration of arsenic in groundwater V0) due to As (V) adsorbed into $FeAsO_4$ surfaces in the sedimentation tank. Precipitated $Fe(OH)_3$ particles which escaped from the sedimentation tank would be retained on the sand layer. When flow passed through the sand layer, As (V) continued to be adsorbed by $Fe(OH)_3$ precipitates in the sand layer, which decreased As (V) in water. The addition of a sprinkler in the third mode promoted the conversion of Fe (II) to precipitated Fe (III) relative to predecessor mode, meaning that arsenic in water was adsorbed more than in the second mode.

This explains why the efficiency of the removal of iron and arsenic in the third mode is higher than in the second mode after sedimentation (V2) and after sand filtration (V3) because the efficiency of arsenic removal through iron hydroxide depends upon the Fe/As ratio in water (the higher the ratio, the higher the efficiency) [7]. In the third mode, a sprinkler was added at the position and pumped into the aeration tank.

The results of the analysis of iron concentrations in water samples indicated that after sand filtration (V3) in the third mode, iron concentration decreased to less than 0.3 mg/l and reached over 96% iron treatment efficiency in the third mode. After iron-rich adsorbents (V4) and activated carbon layer (V5), the iron concentration in the adsorbent column in pilot scale was nearly unchanged relative to the water sample in sand filtration (V3), which indicates that two types of adsorbents (iron-rich adsorbents and activated carbon) were almost not involved in iron treatment and that iron-rich adsorbents were not corroded; iron from iron-rich adsorbent was not to be released into water (Fig. 4).

Effect of height of iron-rich adsorbents on the removal of arsenic in the pilot system

The efficiency of removing arsenic from groundwater in the



(A) **(B)**

Fig. 5. Removal of arsenic in the second and third modes. **(A)** The second mode and (**B**) the third mode.
Note: V0 - groundwater; V5 - treated water.

second mode was about 76%. The concentration of arsenic after overall treatment processes was between 12 and 50 µg/l, which does not fulfil Vietnam's technical regulations concerning drinking water quality. Therefore, the pilot system was developed in the third mode with twice the height of the iron-rich adsorbents relative to the predecessor system (250 mm).

The results of groundwater analysis at Cu Da Nursery School suggest that the concentration of arsenic in groundwater (V0) was between 250 and 400 µg/l. In the second mode, after the sand layer, the concentrations of arsenic in water were between 55 and 90 µg/l; after overall treatment processes (V5), concentrations of arsenic were between 12 and 50 µg/l. After the activated carbon layer (V5), the arsenic concentration in water was nearly unchanged relative to the water sample after iron-rich adsorbents (V4). Figure 5 illustrates the efficiency of arsenic removal in the second and third modes. The results indicate that the efficiency of arsenic removal increased with increasing absorbent packed media. The concentration of arsenic in treated water (V5) decreased to less than 10 µg/l, which fulfils Vietnam's national technical regulations concerning drinking water quality (Fig. 5).

Of the changes in three different operated modes, the third mode corresponds with the most effective removal of iron and arsenic. The results of the analysis of the water samples demonstrated that after the addition of the aeration system, the sprinkler increased the efficiency of the removal of iron and arsenic in groundwater. Fe (II) and As (III) were converted to Fe (III) and As (V) (As (V) is adsorbed by $Fe(OH)_3$ more easily than As (III)). In addition, changing the height of iron-rich adsorbents layer also affected the removal of arsenic from groundwater. With the processes and the 120 mm height of iron-rich adsorbents, the adsorption column in the pilot scale removed 76% of arsenic, while with a 250 mm height of iron-rich adsorbents, the water quality was demonstrated to respond significantly in reducing arsenic by over 94% (to less than 10 µg/l).

Conclusions

In the pilot scale, the efficiency of arsenic removal from groundwater was affected directly by the height of the iron-rich adsorbents layer and the aeration process. After passing through the pilot system, the concentration of arsenic and iron in groundwater decreased to less than 10 µg/l and less than 0.3 mg/l, respectively, and the pH of the treated water samples was slightly increased by the removal of iron of the pilot system and the alkalinity of kaolin in the iron-rich adsorbents (between 6.9 and 7.8). The parameters of pH, As, and Fe in the ground water after treatment fulfilled Vietnam technical regulations concerning drinking water quality. These confirmed that using iron-rich adsorbents to remove arsenic from groundwater in decentralised water supply treatment is an effective method both economically and in terms of ameliorating water quality.

The authors declare that there is no conflict of interest regarding the publication of this article.

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