NOVEL TREATMENT TECHNOLOGIES FOR ARSENIC REMOVAL FROM WATER

By

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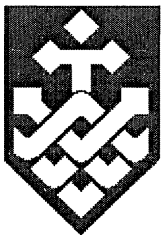

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CERTIFICATE

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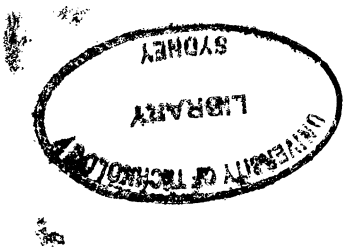

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NOMENCLATURE

b	: constant related to the binding energy of adsorption (L/mg)
BV	: bed volume
C	: solute arsenic concentration (mg/L)
C_b	: desired concentration of adsorbate at breakthrough (mg/L)
C_e	: equilibrium concentration (mg/L)
C_{ef}	: effluent adsorbate concentration (mg/L)
C_{if}	: influent adsorbate concentration (mg/L)
C_o	: initial arsenic concentration (mg/L)
d	: depth of adsorbent's bed (m)
D_x	: dispersion coefficient in x direction (m^2/s)
EBCT	: empty bed contact time
IOCS-2	: Iron oxide coated sand 2
IOCSp	: Iron oxide coated sponge
k_1	: rate constant of BDST model (L/mg.h)
K_d	: linear equilibrium partitioning coefficient (L/mg)
k_F	: Freudlich constant indicative of the adsorption capacity
k_H	: Ho rate constant for adsorption (g/mg.min)
k_N	: mass transfer loss coefficient (1/s)
k_T	: Thomas rate constant (L/min.mg)
m	: amount of adsorbent (g)
n	: experimental constant indicative of the adsorption intensity
n_T	: effective porosity (dimensionless)

NZVI : nanoscale zero valent iron

p_s : solid density of the particles (mg/L)

q_t : amount of adsorbate at any time t, (mg/g)

q_e : amount of adsorbate at equilibrium (mg/g)

q_m : saturated maximum adsorption capacity (mg/g)

Q_v : volumetric flow rate (L/min)

r : correlation coefficient

S : amount sorbed onto porous medium (mg/mg)

SMZ/ZVI : surfactant modified zeolite – zero valent iron

t : service time of column (h)

T : temperature

u_x : velocity of water (m/s)

V : throughput volume (L)

w_a : mass of arsenic adsorbed after time t (mg)

w_a^0 : maximum adsorption capacity of filter (mg)

α : dispersivity (m)

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ABSTRACT

Arsenic is a toxic semi-metallic element that can be fatal to human health. It can have a significant adverse impact on the environment. Arsenic pollution in water has been found in many parts of the world, especially in developing countries such as Bangladesh, India, Nepal, and Vietnam. It is also detected in some areas of Australia. In rural area of Victoria, arsenic concentrations of up to 8 μg/L and 220 μg/L in groundwater and surface water have been reported. The arsenic contamination in water forced the water and health authorities to introduce stringent standards for arsenic levels in drinking water. World Health Organization (WHO) has recommended the arsenic level in drinking water to the stricter level to be 10 μg/L instead of 50 μg/L (since 1993). The U.S. Environmental Protection Agency (EPA) has lowered the maximum contaminant level (MCL) of arsenic from 50 μg/L to 10 μg/L. Rigorous criteria of arsenic level have been enforcing water authorities to identify and put into practice suitable and cost-effective arsenic removal technologies.

The main objectives of the research described in this thesis were to develop and assess the potential and effectiveness of a new adsorbent medium namely iron oxide coated sponge (IOCSp) in removing arsenite [As(III)] and arsenate [As(V)] to an acceptable level in drinking water supplies. Arsenite [As(III)] and arsenate [As(V)] are the two predominant arsenic species found in groundwater. Regeneration of the exhausted IOCSp was also investigated. In addition, two other adsorbents: iron oxide coated sand 2 (IOCS-2), and surfactant modified zeolite – zero valent iron (SMZ/ZVI) were evaluated and their efficiency were compared with that of IOCSp. Effectiveness of membrane and photocatalysis hybrid systems in removing arsenic was studied. In this study, tap water (Sydney, Australia and Regina, Saskatchewan, Canada) spiked with predetermined amounts of As(III) and As(V) was used in the batch, tray and column studies. Raw water containing arsenic from Kelliher, Saskatchewan and Van Phuc Village, Hanoi, Vietnam were also investigated in the study.

The research described below investigated optimised conditions for coating iron oxide on sponge by different coating conditions. Optimum conditions for coating the sponge with iron oxide were as follow: (i) pH value of coating condition of 4 (ii) time of contact between iron oxide and the sponge during coating of 10 hours; (iii) coating

temperature of 110°C; and (iv) time of drying of sponge after the coating of 20 hours. The maximum adsorption capacities of IOCSp for As(III) and As(V) estimated by Langmuir, and Sips models were up to 4.18 and 4.6 mg/g of IOCSp, respectively. More than 92.4% of both As(III) and As(V) was removed after a contact period of 9 hours with the IOCSp (based on batch studies). The IOCSp adsorption equilibrium results with synthetic water fitted reasonably well with Freundlich, Langmuir, and Sips isotherms, indicating favourable adsorption.

The performance of the IOCSp column was experimentally evaluated with synthetic water spiked with arsenic. The results showed that the IOCSp column could maintain high arsenic removal efficiency even after a long filtration time without any need for regeneration. For example, a filter packed even with very small amount of 25 g IOCSp maintained a consistent arsenic removal efficiency of 95% from synthetic water containing arsenic concentration of as high as 1,000 μg/L. This produced a throughput volume of 153 and 178 L of water containing As(III) and As(V) respectively before any need for regeneration or disposal of IOCSp. A relatively small amount of IOCSp (8 g) could treat 42 – 63 L of arsenic contaminated groundwater (56 – 156 μg/L) in Kelliher (Canada) and in Hanoi (Vietnam) to a level of less than 20 μg/L. Studies showed that As(V) removal was better compared with As(III) removal.

The results showed that the performance of IOCSp was superior to than that of iron oxide coated sand (IOCS-2) and surfactant modified zeolite – zero valent iron (SMZ/ZVI) in terms of weight of media. The IOCSp, once exhausted, can be regenerated with a small amount of sodium hydroxide 0.3M. The regenerated IOCSp did not have any significant decrease in removal effectiveness as compared to the fresh IOCSp.

Photooxidation experimental results also showed that photooxidation of As(III) to As(V) with titanium dioxide (TiO_2) as photocatalyst is possible within minutes. Further, TiO_2 can also adsorb both As(III) and As(V) on its surface. Thus, the photocatalysis reaction with TiO_2 can reduce about 98% of arsenite from water containing 500 μg/L of arsenite. By adding nanoscale zero valent iron (nZVI) of 0.05 g/L in the photo reactor, arsenic removal can be significantly enhanced to a value less than 10 μg/L. The amount of TiO_2 used in this photocatalysis hybrid system was only 20% of normal photocatalysis operation.

Removal of arsenic by a membrane is highly dependent on the species of arsenic and the properties of membranes. About 57% of As(III) and 81% of As(V) removal from 500 μg/L arsenic solution could be achieved by nanofiltration (NF) of 700 molecular weight cutoff. This removal efficiency could be increased to more than 95% by an inline addition of 0.2 g/L of nZVI. This method is suitable when high quality effluent is required.

In summary, the study demonstrated conclusively that iron oxide coated sponge is an excellent media for reducing arsenic. IOCSp filter can be used as an effective and economical treatment system in removing arsenic from contaminated groundwater. The merits of the IOCSp filter process are the consistent removal efficiency, long life cycle, and simplicity in operation, regeneration and disposal.