Reduction of low arsenic concentrations in drinking water to below $1 \mu\text{g L}^{-1}$ by adsorption onto granular iron (hydr)oxides

A. Jeworrek¹, A. Ahmad^{1,2,4}, B. Hofs³, J. van Mook³ & A. van der Wal^{1,3}

¹Department of Environmental Technology, Wageningen University and Research (WUR), Wageningen, The Netherlands

²KWR Water Cycle Research Institute, Nieuwegein, The Netherlands

³Department of Watertechnology, Evides Waterbedrijf, Rotterdam, The Netherlands

⁴KTH-International Groundwater Arsenic Research Group, Department of Sustainable Development, Environmental Science and Engineering, KTH Royal Institute of Technology, Stockholm, Sweden

ABSTRACT: Arsenic in drinking water should be reduced as much as possible, because it is amongst carcinogenic substances. FerroSorp® Plus, Huijbergen and Spannenburg GIH could reduce As(V) levels in Ouddorp water below the desired $1 \mu\text{g L}^{-1}$. Particularly Huijbergen GIH had according to non-linear Freundlich modeling the higher K_F value, translating into a potentially higher effective adsorption capacity. One of the characteristics that probably determines the success of a GIH is its physical properties. Since the effective adsorption capacity increases with higher initial As(V) concentrations, Huijbergen GIH is a promising adsorbent to reduce a wide range of arsenic concentrations from drinking water. Therefore, this affordable technology is not only reducing ultra-low arsenic concentrations to even lower concentrations in Ouddorp water but is also promising for developing countries that are seriously affected by high concentrations of arsenic in their drinking water.

1 INTRODUCTION

More than 100 million people worldwide are drinking As contaminated water (Mandal and Suzuki, 2002). Arsenic (As), in concentrations lower than the WHO guideline ($10 \mu\text{g L}^{-1}$), may be toxic to humans (Ahmad *et al.*, 2014; Banerjee *et al.*, 2008). At water treatment plant (WTP) Ouddorp in The Netherlands the produced drinking water contains $3.3 \mu\text{g L}^{-1}$ arsenate (As(V)). According to Vewin (2016), As concentrations in the Dutch drinking water need to be below $1 \mu\text{g L}^{-1}$ by 2020. One of the low-cost options to reduce As concentrations below $1 \mu\text{g L}^{-1}$, is to make use of the adsorption potential of the iron (hydr)oxide-based groundwater treatment residuals (Ahmad *et al.*, 2017; Hofman-Caris *et al.*, 2017; Ociński *et al.*, 2016). In this study we have investigated the As(V) adsorption potential of GIHs originating from different sources.

2 METHODS

2.1 Adsorption isotherms & Freundlich model fitting

In order to determine the adsorption capacities of the GIHs, batch adsorption isotherm experiments were carried out with equilibration time of 114 h. GIHs including FerroSorp® Plus, Huijbergen and Spannenburg were compared. As(V) loadings of 1.1, 11.1,

111.1, 1111.1, 11111.1 and 50001.1 $\mu\text{g As(V)}$ per g GIH were tested at 15°C using Ouddorp water containing only As(V). The experimental results were fitted with the linear and non-linear Freundlich model. K_F and n from the linear plotting ($\log q_e = n \log C_e + \log K_F$) where used for non-linear fitting where the effective adsorption capacity was calculated with the following non-linear Freundlich equation: $q_e = K_F C_e^n$.

3 RESULTS AND DISCUSSION

FerroSorp® Plus Spannenburg and Huijbergen GIH succeeded in reducing the As(V) levels below $1 \mu\text{g L}^{-1}$, with residual As concentrations reaching down to 0.66, 0.68 and $0.86 \mu\text{g L}^{-1}$ respectively (Fig. 1). At an initial As(V) concentration of $3.3 \mu\text{g L}^{-1}$ the effective adsorption capacities per 3 g of GIH were around $2 \mu\text{g As(V)}$ per g GIH for all three adsorbents. All three GIHs can reduce initial As(V) concentrations of $300 \mu\text{g L}^{-1}$ to below the WHO maximum permitted concentration of $10 \mu\text{g As L}^{-1}$ (WHO, 2011). The effective adsorption capacities at $300 \mu\text{g As(V) L}^{-1}$ initial As(V) concentrations are around 98 to $100 \mu\text{g As(V) g}^{-1}$ GIH, making this adsorption technique applicable for a wide range of As(V) concentrations.

Due to a change in chemical equilibrium at higher initial As(V) concentrations in solution, the

Figure 1. Log residual As(V) concentration ($\mu\text{g L}^{-1}$) versus log effective adsorption capacity ($\mu\text{g As(V) g}^{-1}$ GIH) of Ferrosorp® Plus, Huijbergen GIH and Spannenburg GIH in Ouddorp water with a pH of 7.8; experimental data.

Table 1. Values for n , K_F , log SSE and R^2 of the GIH in non-linear model fitting.

GIH	n	K_F^*	log SSE	R^2
Ferrosorp plus	0.79	13.3	0.14	0.96
Huijbergen	0.75	20.8	0.18	0.94
Spannenburg	0.73	12.4	0.12	0.96

* $(\mu\text{g/g})/(\mu\text{g/L})^n$.

experimental effective adsorption capacity of a GIH increases. Huijbergen GIH showed the highest effective adsorption capacity at the different initial As(V) concentrations (Fig. 1).

Huijbergen GIH featured, according to non-linear model fitting the highest K_F value (Table 1), translating into the highest effective adsorption capacity, making it the most suitable GIH to adsorb As(V) in Ouddorp water.

The better effective performance of Huijbergen GIH can probably be explained by its physical parameters: a comparably higher surface area and a more suitable pore size distribution for As(V) adsorption. At pH of 7.8, potential adsorption competition of same charged species (silicate, phosphate) as As(V) was seen, which indicates that the pH and the water matrix collude in determining the effectiveness of an adsorbent.

4 CONCLUSIONS

All tested GIH achieved the desired residual As(V) concentrations below $1 \mu\text{g L}^{-1}$. Nevertheless, Huijbergen GIH showed the higher effective adsorption capacity according to non-linear Freundlich fitting.

GIHs, especially HUY, are therefore not only applicable to reduce low arsenic concentrations below $1 \mu\text{g L}^{-1}$, but also to reduce arsenic concentrations of at least $300 \mu\text{g L}^{-1}$, which makes this affordable adsorption technology interesting for countries such as India or Bangladesh which suffer from high arsenic concentrations in their drinking water sources.

ACKNOWLEDGEMENTS

The authors thank the TKI program of the Dutch Government project for partially financing this research. This work was performed in collaboration with Evides Water Company and KWR Water Cycle Research Institute. The authors like to thank the Arsenic reduction team of Evides for the shared knowledge and input.

REFERENCES

- Ahmad, A., Van De Wetering, S., Groenendijk, M. & Bhattacharya, P. 2014. Advanced Oxidation-Coagulation-Filtration (AOCF) – an innovative treatment technology for targeting drinking water with $<1 \mu\text{g/L}$ of arsenic. *5th International Congress on Arsenic in the Environment, As 2014, Buenos Aires, Argentina, 11–16 May 2014*. CRC Press, pp. 817–819.
- Ahmad, A., Richards, L.A. & Bhattacharya, P. 2017. Arsenic remediation of drinking water: an overview. In: P. Bhattacharya, D.A. Polya & D. Jovanovic (eds) *Best Practice Guide on the Control of Arsenic in Drinking Water*. IWA Publishing UK, pp. 79–98.
- Banerjee, K., Amy, G., Prevost, M., Nour, S., Jekel, M., Gallagher, P. & Blumenschein, C. 2008. Kinetic and thermodynamic aspects of adsorption of arsenic onto granular ferric hydroxide (GFH). *Water Res.* 42(13): 3371–3378.
- Hofman-Caris, R., Ahmad, A., Siegers, W., Rahn, S., Voort, J. & van der Kolk, O. 2017. *Pelletized drinking water treatment residuals for the removal of arsenic and phosphate from water*. KWR Water Research Institute.
- IARC. 2012. Arsenic and arsenic compounds. *IARC*, 100 C 6.
- Mandal, B. & Suzuki, K. 2002. Arsenic round the world: a review. *Talanta* 58(1): 201–235.
- Ociński, D., Jacukowicz-Sobala, I., Mazur, P., Raczky, J. & Kociłek-Balawejder, E. 2016. Water treatment residuals containing iron and manganese oxides for arsenic removal from water – characterization of physicochemical properties and adsorption studies. *Chem. Eng. J.* 294: 210–221.
- Vewin. 2016. *Kerngegevens Drinkwater*.
- WHO. 2011. *Guidelines for drinking-water quality*, 4th Edition. World Health Organization, Geneva.