

## Effect of groundwater quality on adsorptive iron removal

S. K. Sharma, C. Sebwato, B. Petrusevski and J. C. Schippers

### ABSTRACT

Adsorptive iron removal from groundwater involves the adsorption of iron(II) onto the surface of the filter media and the subsequent oxidation of adsorbed iron(II) in the presence of oxygen to regenerate the adsorption site for the continuation of the process. Different ions and compounds present in groundwater might influence iron(II) adsorption onto filter media. Laboratory scale batch adsorption experiments were conducted to investigate the effect of major inorganic ions present in groundwater, i.e.  $Mn^{2+}$ ,  $Ca^{2+}$ ,  $NH_4^+$ ,  $SO_4^{2-}$ ,  $Cl^-$ , alkalinity and background ionic strength on the iron(II) adsorption onto new silica sand and iron oxide coated sand. Alkalinity, background ionic strength,  $NH_4^+$  and  $Cl^-$  had no significant effect on iron(II) adsorption onto both the media tested. An increase in concentration of  $Mn^{2+}$  and  $Ca^{2+}$  decreased the iron(II) adsorption onto new sand whereas an increase in iron(II) adsorption was observed when  $SO_4^{2-}$  concentration was increased. The effect of  $Mn^{2+}$ ,  $Ca^{2+}$  and  $SO_4^{2-}$  on iron(II) adsorption onto iron oxide coated sand, however, was minimal. This indicates that once the iron oxide coating is developed, iron(II) adsorption is not significantly hindered due to the presence of other inorganic ions in concentrations common in groundwater.

**Key words** | adsorption, groundwater, iron oxide coated sand, iron removal, water quality

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### INTRODUCTION

Groundwater is a major source of drinking water in many countries across the world. Iron, being the fourth most abundant element in the earth crust (Silver 1993; WHO 1996), is a common constituent of groundwater. Bad taste, discoloration, staining, deposition in distribution systems leading to aftergrowth, and incidences of high turbidity are some of the aesthetic and operational problems caused by iron in water supplies (O'Connor 1971; Vigneswaran & Visvanathan 1995). WHO recommends the guideline value of iron in drinking water as 0.3 mg/l (WHO 1996) and the EC has set a maximum admissible concentration of 0.2 mg/l (EC 1998). In the Netherlands, the guideline level of iron in drinking water is less than 0.05 mg/l (VEWIN 1993).

Conventionally, iron is removed from groundwater by the processes of aeration and rapid filtration (O'Connor 1971; Salvato 1992). Two main physicochemical removal mechanisms, namely oxidation-floc formation (floc filtration) and adsorption-oxidation (adsorptive filtration),

play an important role in the removal process (Sharma *et al.* 2001). In floc filtration, soluble iron(II) present in groundwater is oxidized to insoluble iron(III) and the flocs formed are removed in filters. In adsorptive filtration, the iron(II) present in anaerobic groundwater is removed by adsorption onto the surface of the filter media. The adsorbed iron(II) is oxidized in the presence of oxygen thus creating a new surface for adsorption for the continuation of the process. Under commonly applied treatment conditions in iron removal plants, the floc filtration mode predominates. The adsorptive filtration mode of iron removal, however, has several advantages over the floc filtration mode. It results in a very low head loss development in comparison with floc filtration as the iron forms a coating rather than flocs. Thus the filter runs are longer and the backwash water requirement and the volume of the sludge produced are reduced.

Adsorption of iron(II) onto iron hydroxide flocs and iron oxide coated sand (IOCS) is well known (O'Connor

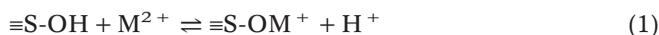
1971; Hult 1973; Takai 1973; Tamura *et al.* 1976; Braester & Martinell 1988; Appelo *et al.* 1999). Over time, iron oxide coatings develop on the surface of the filter media used in iron removal. Previous studies showed that iron(II) adsorption onto filter media increases with increase in pH and, compared to new sand, IOCS has a very high capacity for iron(II) adsorption (Sharma *et al.* 1999). This high iron(II) adsorption capacity of IOCS can be utilized to improve iron removal in filters by operating the filter predominantly in adsorptive mode. However it is unclear how a specific groundwater composition, or a specific ion or compound present, will influence the effectiveness of adsorptive iron removal.

Several ions present in natural groundwater like  $Mn^{2+}$ ,  $Ca^{2+}$ ,  $NH_4^+$ ,  $Cl^-$ ,  $SO_4^{2-}$ ,  $PO_4^{3-}$ , etc. and other water quality parameters such as alkalinity, TOC and temperature, might influence the iron(II) adsorption. These ions may mutually compete with each other for adsorption sites or may enhance, decrease, or even inhibit the adsorption of iron(II) thereby influencing the overall efficiency of adsorptive iron removal (Weber 1972; Faust & Aly 1998). Secondly, adsorptive iron removal is more effective after the development of the iron oxide coating on filter sand. The above-mentioned water quality parameters can also influence the rate of the coating development by affecting the adsorption onto the surface of new sand. Additionally, ions adsorbed onto the sand surface may influence the physicochemical characteristics of the coating thus influencing the iron(II) adsorption capacity. These ions might also affect the rate of oxidation of adsorbed iron(II), and consequently the regeneration of adsorption sites. Hence, studying the effect of water quality parameters on iron(II) adsorption and its regeneration is important for the successful exploitation of the adsorption-oxidation mechanism of iron removal. This paper focuses on the effect of some major groundwater quality parameters such as  $Mn^{2+}$ ,  $Ca^{2+}$ ,  $NH_4^+$ ,  $SO_4^{2-}$ ,  $Cl^-$ , alkalinity and background ionic strength on the adsorption of iron(II) onto new silica sand and IOCS.

### Theoretical background

The hydrated surface of oxides (silica sand and IOCS) can adsorb cations and anions present in the water. The extent

of adsorption depends on the type and density of the adsorption sites available and the nature of the adsorbing ion. Cation surface complexation by hydrous oxides involves formation of bonds with surface oxygen atoms and the release of protons from the surface, as represented by Equations (1) and (2).



or equivalently:



where  $\equiv S-OH$  and  $M^{2+}$  represent the hydrated oxide surface and a divalent cation respectively (Dzombak & Morel 1990).

Anion adsorption by hydrous oxide occurs via ligand exchange reactions in which hydroxyl surface groups are replaced by the sorbing ions (Dzombak & Morel 1990).



and/or



where  $A^{2-}$  represents a divalent anion.

Ionic charge and size have an important role in cation sorption. Other things being equal, the adsorption affinity is greater for the ion with higher valency. For the ions of the same valence the affinity for adsorption increases with atomic number and apparently decreases with decreasing ionic size (Matthess 1982). Simultaneous adsorption of different cations involves competition between the cations for the available adsorption sites since adsorption from solution is usually restricted to a monolayer (Faust & Aly 1998). In the presence of other cations like  $Ca^{2+}$ ,  $Mn^{2+}$ , etc., commonly present in groundwater, the adsorption sites available for iron(II) may be reduced and therefore a reduction in its adsorption is expected. Mutual inhibition can be predicted to occur if adsorption is confined to a single or a few molecular layers, the adsorption affinities of the solutes do not differ by several orders of magnitude and there is

**Table 1** | Characteristics of the new sand and IOCS used

	New sand	IOCS
Grain size (mm)	0.8–1.25	0.8–1.25
Effective size $d_{10}$ (mm)	0.82	0.82
Specific surface area (BET) ( $m^2/g$ )	1.0	7.7
Surface extractable iron content (mg/g sand)	0	22.3

no specific interaction between solutes enhancing adsorption. The degree of mutual inhibition is related to relative sizes, concentrations, and adsorption affinities of the competing molecules (Weber 1972).

There are four ways in which ligands, which are mostly anions, can affect adsorption of metal ions onto oxide surfaces (Benjamin & Leckie 1982):

- i. Metal-ligand complexes may form in solution and adsorb only weakly or not at all.
- ii. The species may interact indirectly at the surface, thereby altering the surface electrical properties.
- iii. The metal-ligand complex may adsorb strongly, thereby enhancing the adsorption of the metal ions.
- iv. The formed complex may have no effect on metal adsorption.

Hence, depending on the nature of the anions present and complexes formed, iron(II) adsorption onto filter media may be enhanced, decreased or unaltered.

## MATERIALS AND METHODS

### Filter media

New (virgin) silica sand and IOCS developed in the laboratory were used in this study. The characteristics of the filter media used are presented in Table 1. The new sand was washed in de-mineralized water, soaked in hydrochloric acid ( $pH < 2$ ) for 24 hours and again rinsed with de-mineralized water and dried at  $40^\circ C$ .

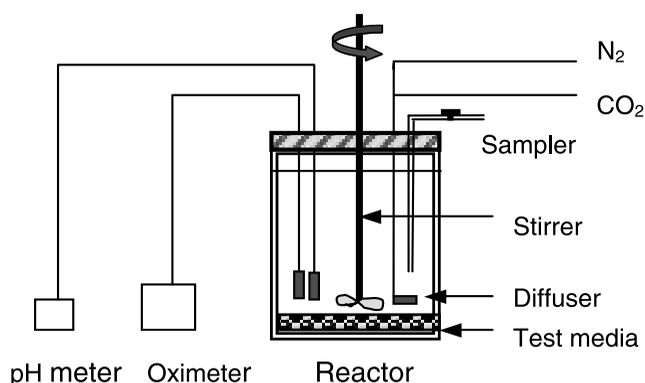
**Table 2** | Chemicals used to introduce different water quality parameters

Chemical	Purpose
$NaHCO_3$	Alkalinity and pH control
$FeSO_4 \cdot 7H_2O$	Iron(II) source
$MnSO_4 \cdot H_2O$	Manganese source
$Ca(NO_3)_2 \cdot 4H_2O$	Calcium source
$NH_4Cl$	Ammonium source
$Na_2SO_4$	Sulphate source
$NaCl$	Chloride source
$NaNNO_3$	Background ionic strength

The IOCS was developed by running a pilot filter at a pH of  $7.1 \pm 0.1$  with feed water iron(II) concentration of  $6.0 \pm 0.2$  mg/l at a filtration rate of  $5 \pm 0.5$  m/h over a run time of 1500 hours. The details of the process of coating development and characteristics of the coating are presented elsewhere (Sharma *et al.* 2000). The IOCS developed was washed with de-mineralized water gently to remove any deposits and dried at room temperature before being used for batch experiments.

### Experimental set up

Iron(II) adsorption onto new sand and IOCS was measured at different concentrations of parameters under study by conducting batch adsorption equilibrium experiments at room temperature ( $18-20^\circ C$ ). The experimental set-up used to determine iron(II) adsorption onto filter media, as shown in Figure 1, was similar to that used in an earlier study (Sharma *et al.* 1999). The experimental apparatus consisted of a sealed 2-litre glass reactor. The vessel cover had ports to allow solution feeding and sampling, oxygen, temperature and pH measurement, gas supply and mechanical stirring. Nitrogen gas was used for deoxygenation and the purging of the gas was continued throughout the experiment. The pH was adjusted using  $HCO_3^- - CO_2$



**Figure 1** | Batch experimental set-up.

buffer. The pH and oxygen concentration were monitored continuously.

Table 2 shows the different chemicals used to introduce different ions/water quality parameters into the model groundwater. All the chemicals used were of reagent grade.

### Experimental procedure

Initially 1.5 litres of de-mineralized water were deoxygenated by bubbling nitrogen gas through the solution. The pH was adjusted to the desired level with  $\text{HCO}_3^-$  and  $\text{CO}_2$  gas. Then 15 ml of 400 mg/l deoxygenated iron(II) stock solution, and the varying amount of stock solution of the parameter under study, were dosed into the closed reactor containing deoxygenated water and 40–50 g of filter media. The pH during the experiment was controlled to within 0.05 units. The solution in the reactor was mixed using a mechanical stirrer. The media remained settled on the bottom of the vessel. This avoided scouring of any surface coating. On equilibrium, concentrations of iron(II) and the parameter under study in the reactor were measured (Standard Methods 1995) and the amount of iron(II) adsorbed onto the media was calculated by a mass balance. All the experiments were carried out in duplicate to verify the reproducibility of the results.

The equilibration time for each filter media was determined by measuring the hourly variation in iron concentration in the solution. Equilibrium was considered as

being reached when the difference in iron concentrations of two consecutive hourly samples was less than 0.05 mg/l. Under the given experimental conditions, the equilibration times for new sand and IOCS were 4 hours and 7 hours respectively.

## RESULTS AND DISCUSSION

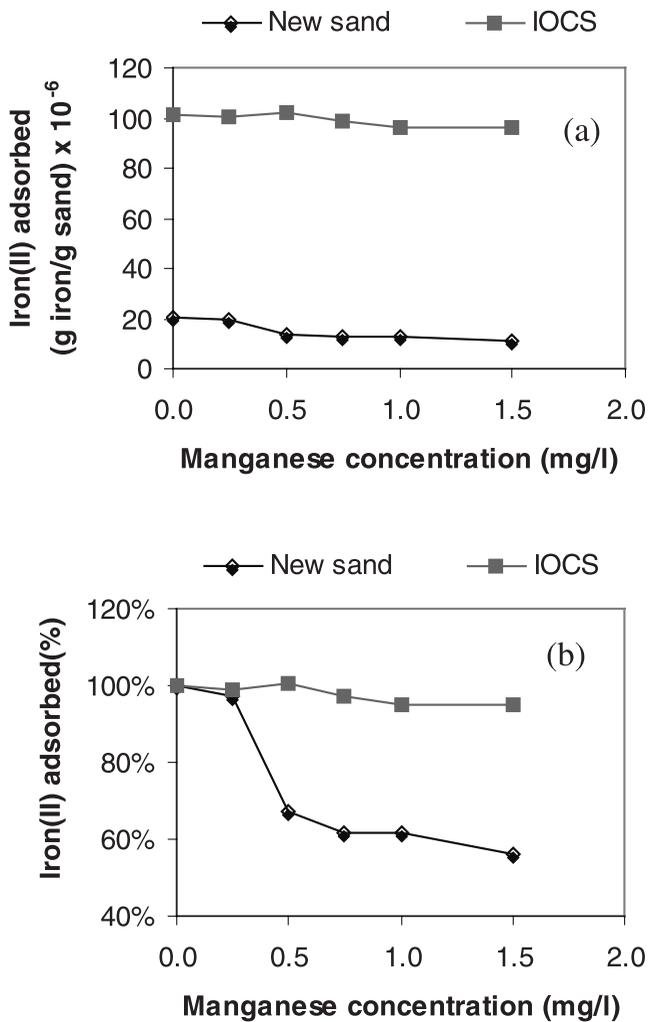
### Effect of manganese

Figure 2 presents the influence of  $\text{Mn}^{2+}$  concentration on iron(II) adsorption onto filter media. Iron(II) adsorption decreased by 44% for new sand and by 6% for IOCS when the  $\text{Mn}^{2+}$  concentration increased from 0 mg/l to 1.5 mg/l (Figure 2b). This reduction in iron(II) adsorption in the presence of  $\text{Mn}^{2+}$  may be due to competitive adsorption between iron and manganese ions. Additionally, introduction of positively charged ions reduces the negative charge of the sand surface resulting in a reduced coulombic force and hence reduced iron(II) adsorption.

Monitoring of the  $\text{Mn}^{2+}$  concentration in the solution confirmed that  $\text{Mn}^{2+}$  gets adsorbed onto IOCS (Figure 3), however there was no measurable adsorption of  $\text{Mn}^{2+}$  onto new sand. Similar findings have been reported in other studies (Graveland & Heertjes 1975; Knocke *et al.* 1988). It was also found that  $\text{Mn}^{2+}$  adsorption onto IOCS increases with the increase of pH from 6.0 to 7.5. These results indicate that some manganese removal by adsorption onto IOCS can be achieved during adsorptive iron removal. Because of the high adsorption capacity of IOCS and low  $\text{Mn}^{2+}$  concentration normally present in groundwater (manganese to iron in groundwater normally ranges from 1/10 to 1/20),  $\text{Mn}^{2+}$  adsorption onto IOCS would not reduce the adsorption of iron(II) appreciably. Therefore the effect of  $\text{Mn}^{2+}$  on iron(II) adsorption onto IOCS is minimal (Figure 2b).

### Effect of calcium

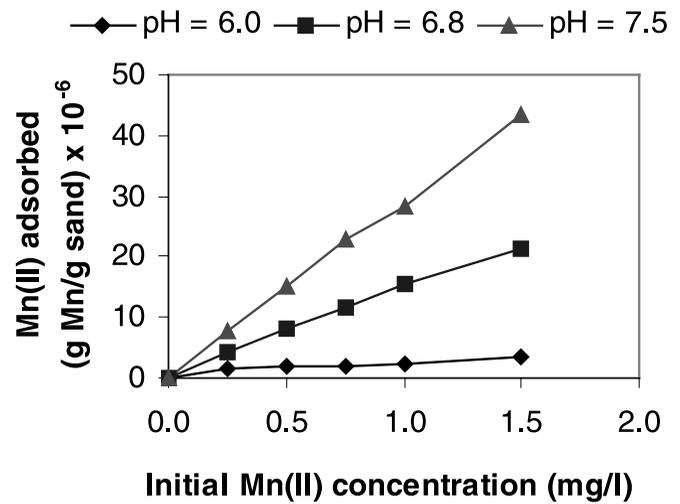
Elevated  $\text{Ca}^{2+}$  concentration inhibits adsorption of iron(II) onto both new sand and IOCS (Figure 4). A reduction in iron(II) adsorption onto new sand and IOCS of 74% and 29% respectively was observed when the  $\text{Ca}^{2+}$  concentration was increased from 0 to 200 mg/l



**Figure 2** | Effect of  $Mn^{2+}$  concentrations on iron(II) adsorption onto new sand and IOCS ( $pH=6.8 \pm 0.05$ , initial iron concentration = 3.96 mg/l).

(Figure 4b). IOCS has much higher iron(II) adsorption capacity than new sand and consequently reduction of iron(II) adsorption due to calcium ions was less pronounced for IOCS compared to new sand.

$Ca^{2+}$  and  $Fe^{2+}$  are both divalent ions therefore their competition for the adsorption sites may depend on their size and concentration. The calcium ion is relatively large (ionic radius 99 pm), can be hydrated, and forms various aqueous complexes with some other inorganic ions (Matthess 1982). In addition, the  $Ca^{2+}$  concentration was far higher than the iron concentration in all cases, and



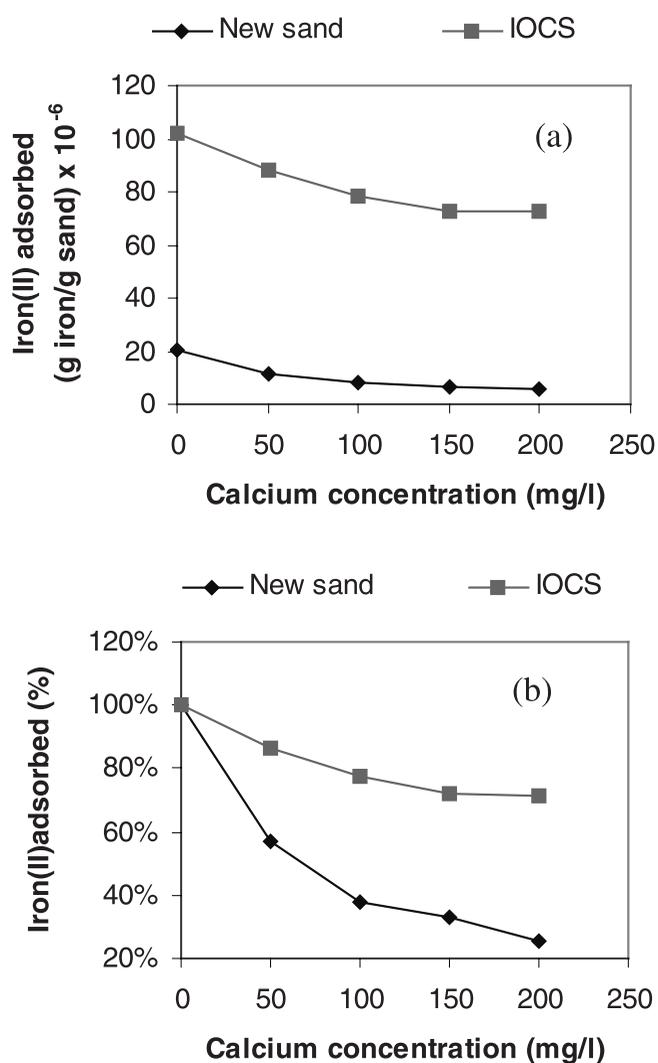
**Figure 3** | Adsorption of manganese onto IOCS at different pH (initial iron concentration = 3.96 mg/l).

hence iron(II) adsorption inhibition could be expected. At pH 6.8 and alkalinity of 6 mmol  $HCO_3^-$  /l, for all calcium concentrations studied the Langlier saturation index was negative indicating that no precipitation of  $CaCO_3$  onto filter media could be expected. No measurable change in calcium concentration during the experiment was observed, confirming previous assumptions.

Experimental results suggest that adsorptive iron removal from hard groundwaters may be rather less efficient as the calcium ion has a negative effect on iron(II) adsorption. However, for waters with a calcium concentration of 50 mg/l, adsorption of iron(II) onto IOCS is only reduced by 10%. In comparison, the performance of floc filtration iron removal from soft waters is poor (Hult 1973) due to slow iron(II) oxygenation and formation of weak flocs. In such cases, adsorptive iron removal may be a better option. On the other hand, iron removal by the floc formation method is better and easier in hard waters than in soft waters because of the possible siderite ( $FeCO_3$ ) precipitation and increased oxygenation rate (Hult 1973).

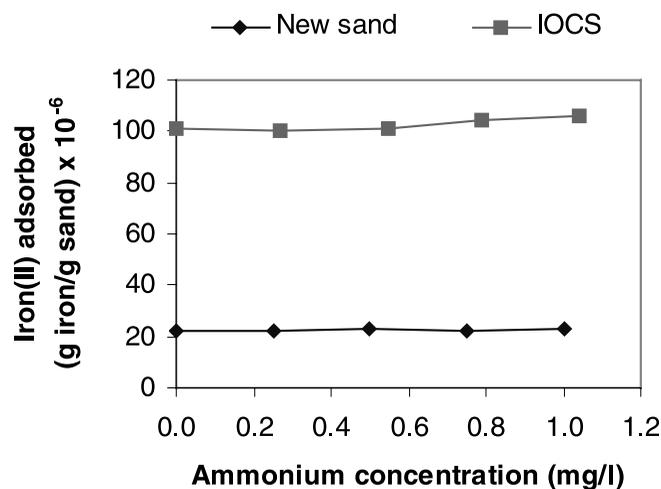
#### Effect of ammonium

An increase in ammonium concentration from 0 mg/l to 1.0 mg/l had no significant effect on adsorption of iron(II)



**Figure 4** | Effect of  $\text{Ca}^{2+}$  concentrations on iron(II) adsorption onto new sand and IOCS (pH=6.8±0.05, initial iron concentration=3.96 mg/l).

onto both new sand and IOCS (Figure 5). Furthermore, no adsorption of ammonium onto new sand was detected. The surface of new sand preferentially adsorbs divalent ions like iron(II) as opposed to monovalent ions like ammonium. Moreover new sand has a low iron(II) adsorption capacity (Sharma *et al.* 1999). Ammonium does not form complexes with iron(II) and hence it does not influence iron(II) speciation. Therefore the presence of ammonium has no effect on adsorption of iron(II) onto new sand. It was also observed that some ammonium was

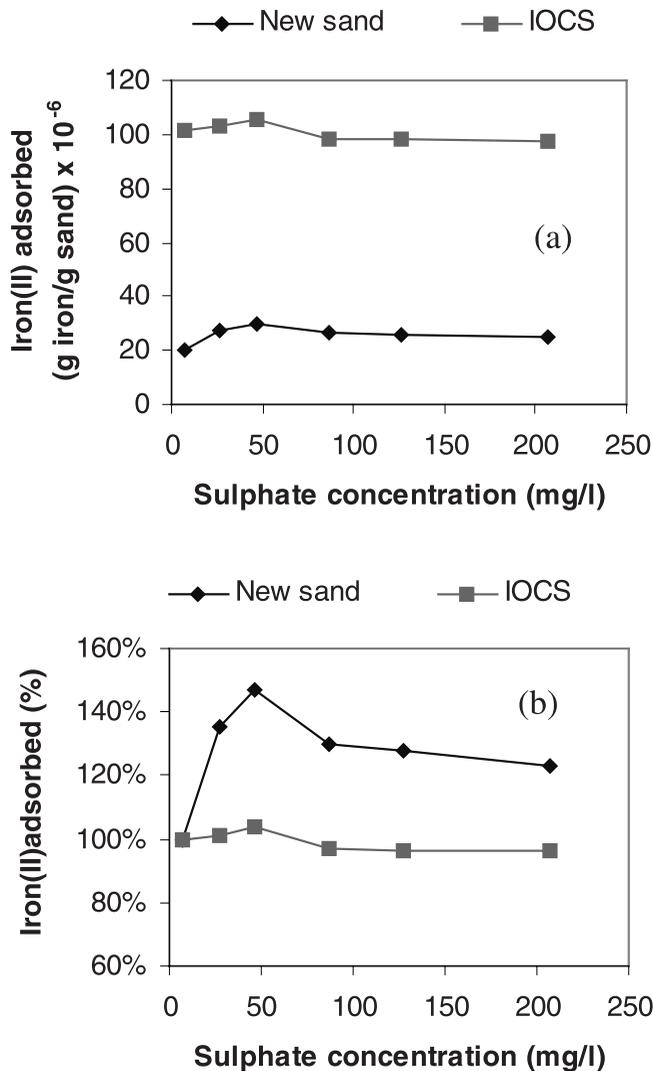


**Figure 5** | Effect of  $\text{NH}_4^+$  concentrations on iron(II) adsorption onto new sand and IOCS (pH=6.8±0.05, initial iron concentration=3.96 mg/l).

adsorbed onto IOCS when the ammonium concentration exceeded 0.25 mg/l. The ammonium adsorption capacity of IOCS under the batch conditions tested was found to be  $7.0 \times 10^{-6}$  g ammonium/g IOCS at an initial ammonium concentration of 1 mg/l.

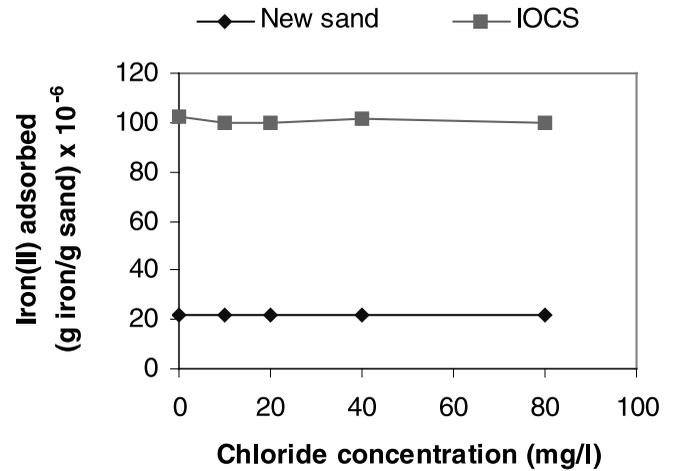
#### Effect of sulphate

Figure 6 illustrates the influence of  $\text{SO}_4^{2-}$  on iron(II) adsorption onto new sand and IOCS. In contrast to divalent cations,  $\text{SO}_4^{2-}$  at lower concentrations (up to 50 mg/l) increased the iron(II) adsorption capacity of both new sand and IOCS (Figure 6). At an  $\text{SO}_4^{2-}$  concentration of 50 mg/l, the iron(II) adsorption increased by 47% and 5% for new sand and IOCS respectively (Figure 6b). Further increases of  $\text{SO}_4^{2-}$  concentrations above 50 mg/l resulted in a reduction of iron(II) adsorption onto both new sand and IOCS, probably due to complexation of iron(II) with  $\text{SO}_4^{2-}$ . Nevertheless, even at the highest  $\text{SO}_4^{2-}$  concentration tested (207 mg/l), the iron(II) adsorbed was 23% greater on the new sand and only 4% less on IOCS in comparison to that at  $\text{SO}_4^{2-}$  concentration of 7 mg/l (Figure 6b). Hence there is considerable increase in iron(II) adsorption onto new sand in the presence of  $\text{SO}_4^{2-}$ , and no significant  $\text{SO}_4^{2-}$ -induced hindrance on the iron(II) adsorption onto IOCS.



**Figure 6** | Effect of  $\text{SO}_4^{2-}$  concentrations on iron(II) adsorption onto new sand and IOCS (pH=6.8±0.05, initial iron concentration=3.96 mg/l).

The initial increase in iron adsorption with increase in sulphate concentration may be due to sulphate adsorption onto the sand oxide surface. Sulphate adsorption onto the filter media changes the oxide surface electrical properties, promoting coulombic interaction between the media surface and iron(II). The eventual decrease in iron(II) adsorption at a sulphate concentration >50 mg/l may be due to formation of the iron sulphate ( $\text{FeSO}_4$ ) ion pair, i.e. sulphate starts competing with the oxide surface for the available iron ions. This increases the solution activity of



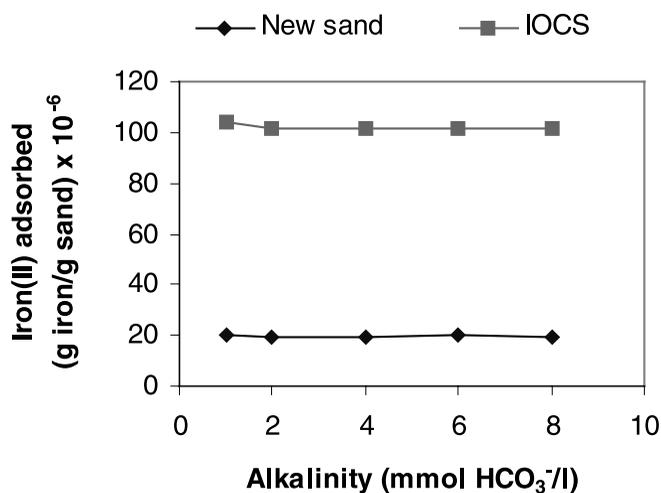
**Figure 7** | Effect of  $\text{Cl}^-$  concentrations on iron(II) adsorption onto new sand and IOCS (pH=6.8±0.05, initial iron concentration=3.96 mg/l).

the ion pair but reduces the amount of iron(II) available for adsorption. Benjamin and Leckie (1982) also reported a reduction in cadmium adsorption onto iron oxide with increase in sulphate concentration.

The increased iron(II) adsorption onto new sand at high sulphate concentration is an indication of the importance of coulombic interaction in the case of new sand. In the case of IOCS, only a 5% increase was observed, re-emphasising the negligible contribution of the coulombic forces in the adsorption of iron(II) onto IOCS. The point of zero charge of hydrous iron oxide lies between pH 7.8 and 8.2 (Dzombak & Morel 1990). It should be noted that at pH of 6.8, IOCS has a positive charge implying that adsorption of iron(II) is taking place against coulombic forces.

### Effect of chloride

For both new sand and IOCS, no significant effect on iron(II) adsorption was observed when the chloride concentration was increased from 0 to 80 mg/l (Figure 7). Additionally, no measurable decrease in the chloride concentration was observed during the experiments. Chloride ions being monovalent are generally located in the diffuse layer and the bulk solution (Stumm & Morgan 1981) and may not form inner-sphere bonds with hydrous oxide surfaces. They do not therefore influence iron(II)



**Figure 8** | Effect of alkalinity on iron(II) adsorption onto new sand and IOCS (pH=6.8±0.05, initial iron concentration=3.96 mg/l).

adsorption, which is adsorbed to specific oxide surface sites.

It is interesting to note that chloride, which is known to form more stable complexes with iron(II) than sulphate, did not affect iron(II) adsorption. In the case of sulphate, the formation of the iron sulphate ion pair changes the adsorption trend. Lack of influence of iron-chloride complexes on iron(II) adsorption may be attributed to the complexes formed being metal-like, and their adsorption is likely to be similar to adsorption of iron(II) ions.

### Effect of alkalinity

An increase in alkalinity from 1 mmol HCO<sub>3</sub><sup>-</sup>/l to 8 mmol HCO<sub>3</sub><sup>-</sup>/l did not show any significant effect on the adsorption of iron(II) onto filter media (Figure 8). It is to be noted that in these experiments pH was maintained at a constant level.

Theoretically, adsorption of cations liberates protons as per Equation (1), resulting in a pH change depending on the buffer capacity. This would in turn affect the iron(II) adsorption process, which is strongly pH dependent (Sharma *et al.* 1999). For waters with high alkalinity of 5.0 mmol HCO<sub>3</sub><sup>-</sup>/l, the resulting pH change with iron(II) adsorption would be 0.02 units for IOCS and negligible for new sand. In the case of waters with low

alkalinity of, for example, 1.0 mmol HCO<sub>3</sub><sup>-</sup>/l, the pH changes would be 0.08 units for IOCS and 0.02 units for new sand, which are still insignificant.

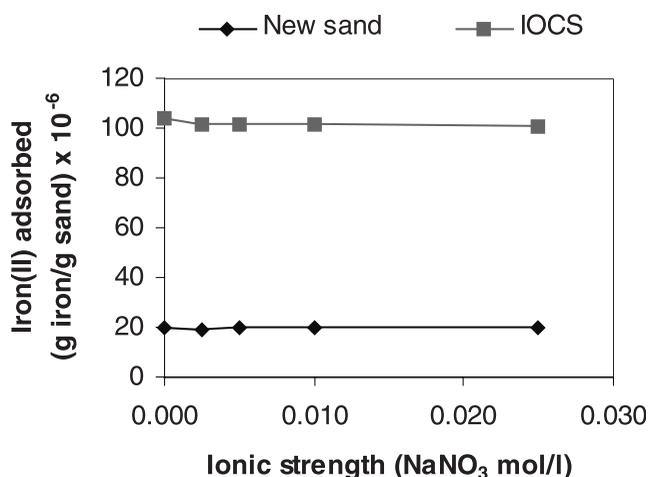
Iron removal by the floc formation-filtration mechanism gives poor results at low alkalinity (Robinson & Breland 1968; Hult 1973) due to slow oxidation and poor floc formation. Secondly, iron content in groundwater is inversely proportional to the alkalinity due to siderite (FeCO<sub>3</sub>) solubility limitations (O'Connor 1971), and higher iron content is expected in groundwater with low alkalinity. The experimental results demonstrated that alkalinity has no significant effect on iron(II) adsorption onto both new and coated sand. This implies that, unlike floc filtration iron removal, adsorptive iron removal is viable even for groundwater with low alkalinity.

### Effect of background ionic strength

While studying the effect of a parameter, ions other than those targeted were also introduced into the model water. In order to ensure that the observed effects were actually due to particular parameters and not due to the change in the ionic strength, the effect of ionic strength on iron(II) adsorption onto filter media was studied. All the anions studied in the experiments were introduced as sodium salts. NO<sub>3</sub><sup>-</sup> is known as a fairly inert and non-complexing ligand. Hence NaNO<sub>3</sub> was selected to vary the background ionic strength of the model groundwater.

It is clear from Figure 9 that an increase in background ionic strength from 0 to 0.025 M NaNO<sub>3</sub> has no effect on iron(II) adsorption onto new sand and IOCS. This is consistent with the findings of other researchers that ionic strength has no effect on cation adsorption onto oxide surfaces (Swallow *et al.* 1980; Hayes & Leckie 1987; Dzombak & Morel 1990). These results also imply that neither Na<sup>+</sup> nor NO<sub>3</sub><sup>-</sup> ions had any influence on iron(II) adsorption onto filter media.

Theoretically, if the coulombic component of the adsorption force were of any importance, one would expect ionic strength to influence adsorption of iron(II). However, the range of ionic strength considered in this study is relatively low (up to 0.025 M) but typical for natural groundwaters. Dzombak & Morel (1990) mention that the absence of ionic strength effect on cation



**Figure 9** | Effect of background ionic strength on iron(II) adsorption onto new sand and IOCS (pH=6.8±0.05, initial iron concentration=3.96 mg/l).

adsorption is because the adsorption occurs against coulombic forces.

### Practical implications

Experimental results reveal that ammonium, chloride, alkalinity and background ionic strength have no effect on adsorptive iron removal. It was also found that within the concentration range of natural groundwater, the effect of manganese, calcium and sulphate on iron(II) adsorption onto IOCS is minimal. For groundwaters containing both manganese and sulphate at concentrations of less than 1.0 and 50 mg/l respectively, the net effect on iron(II) adsorption onto new sand is likely to be insignificant as the decrease in iron adsorption due to manganese is compensated by an increase in iron adsorption due to sulphate. It was also observed that some manganese and ammonium removal takes place during adsorptive iron removal. This implies that in adsorptive iron removal, adsorption of iron(II) onto IOCS is not hindered significantly due to the presence of other inorganic ions at concentrations common in natural groundwater.

As iron(II) adsorption is not influenced by alkalinity, adsorptive iron removal could be a better alternative in case of waters with low alkalinity for which iron removal with floc filtration is difficult. Adsorptive iron removal may be somewhat less efficient in hard waters as calcium

inhibits iron(II) adsorption on new sand and IOCS. Adsorptive iron removal could be very attractive in situations where two filtration steps are needed due to high concentrations of iron, manganese and ammonia. The first filter can be optimized as an adsorptive iron removal filter whilst the second filter can be employed for manganese and ammonia removal.

### Development of iron oxide coating on filter sand

Development of an iron oxide coating with high iron(II) adsorption capacity is a prerequisite for the successful application of adsorptive iron removal mechanism. Knowing the influence of each parameter on iron(II) adsorption onto new sand, the coating development can be predetermined and enhanced if required. Results obtained suggest that coating development on new sand is probably faster in water with a high sulphate concentration and presumably slower in water with high manganese and calcium concentrations. Therefore, addition of sulphate salt to feed water might be a strategy to speed up the coating development on new sand.

It should be noted that the presence of other groundwater constituents not considered in this study might also affect the adsorption process. Phosphates, silica and organic matter, which have a high complexing ability, may significantly hinder or enhance iron(II) adsorption onto filter media. Secondly, the rate of oxidation of iron(II) adsorbed onto filter media might be influenced by the presence of other ions in the water. Understanding the rate and factors affecting the recreation of adsorption sites is, therefore, equally important.

### CONCLUSIONS

- Iron(II) adsorption onto new silica sand was not significantly influenced by alkalinity, background ionic strength,  $\text{NH}_4^+$  and  $\text{Cl}^-$  ions. Increasing concentrations of  $\text{Mn}^{2+}$  and  $\text{Ca}^{2+}$  decreased iron(II) adsorption onto new sand whereas an increase in iron(II) adsorption was observed when  $\text{SO}_4^{2-}$  concentration was increased.

- Alkalinity, background ionic strength,  $\text{NH}_4^+$  and  $\text{Cl}^-$  had no significant effect on iron(II) adsorption onto iron oxide coated sand while the effect of  $\text{Mn}^{2+}$ ,  $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$  was minimal.
- In general, once the iron oxide coating is fully developed on the filter media, the adsorption of iron(II) is not hindered significantly due to the presence of other inorganic ions within the concentration ranges common for groundwater.

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