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Efficient removal of iron from groundwater by dual-media filter

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ABSTRACT

Directly from the coasts of Mediterranean and Red Seas in Egypt by sieving; the *Amphistegina* tests (hard parts or shells) were accumulated in main size of 1.2 mm. While after 18 d of seawater-softening, a definite calcite ooids were formed within an assembled semi-pilot seawater-softening unit with mesh size varying from 0.5 to 3.0 mm. For the first time, we used the *Amphistegina* tests and the fabricated calcite ooids as dual filtration media and iron removal from the groundwater sample presented from Al-Qurayyat, Jouf Governorate, Kingdom of Saudi Arabia. At temperatures of 293 and 313 K and different pumping speeds; 0.02, 0.03, 0.04, 0.05 and 0.06 m^3/h, the filtrate of raw groundwater sample was achieved by different filtration media such as ooids, *Amphistegina* and dual *Amphistegina*-ooids filter. The maximum bed capacity for the dual-media filter vessel, which desired to full of is 13.2 L. This vessel has two layers of media includes ooids (2.28 L) and *Amphistegina* (5.97 L). At lower velocity (0.02 m^3/h) and higher temperature (313 K), the iron removal efficiency reached to 74.15% by new dual-media filter from 1.47 mg/L in raw groundwater sample in the absence of chlorine injection.

Keywords: Water treatment; Groundwater; Calcite ooids; *Amphistegina* tests; Filtration media; Iron removal

1. Introduction

Arab countries represent more than 5% of the world's population, but they own less than 1% of the world's water resources. So, frequent droughts have significantly reduced the availability of renewable and non-renewable water resources. The resort to the use of groundwater has become very urgent. Generally, groundwater treatment, is the process of identifying and treating groundwater contamination problems and also finding the best way to solve potentially health hazardous and ecological problems for whole communities [1–3].

Al-Qurayyat city in Jouf region is an entire arid area in KSA located in the North. Groundwater plays an important role in water supply in the region. There the main water source (groundwater) is considered as a traditional water source and the purification is a non-traditional source [4,5].

Reverse osmosis membranes have very sensitive surfaces to groundwater contents such as organic matters, turbidity, salinity and biological contents. But the more important constituent in groundwater is iron which give rise to membrane fouling and clogging. So, in the designing of groundwater plants, we need to improve the performance and extend the lifetime of membrane by introducing pretreatment stage contains one and/or more steps for iron removal [6–8].

In a previous study, Aly et al. [9] removed iron from groundwater using different techniques. They injected different dosages of chlorine (0.5–2.75 mg/L), and the efficiency of iron removal (3.8 mg/L) rapidly increased to nearly maximum removal (100 %) within 20 min. with the

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optimum dosage (2.75 mg/L). Obviously in groundwater treating that containing organic matters by chlorine injection may not be recommended due to the possibility formation of disinfection by-products. Also the presence of residual free chlorine will cause a more serious membrane fouling and a premature membrane failure and the FilmTec membrane recommends that free residual chlorine must be removed by other appropriate pretreatment method prior to the exposure of membrane surface (free chlorine tolerance; <0.1 ppm).

As new mono-media of pretreatment filtration stage in seawater desalination plant, *Amphistegina* tests are effective in iron removal especially with activated carbon filter [10–12]. Also the same mono-filtration media give a great achievement in iron removal from aqueous solutions reached to 3.64 mg/g [13]. While the other recent mono-filtration media (calcite ooids) were also used in the pretreatment stage of seawater desalination plant in combined with activated carbon filter for producing a better iron removal efficiency reached to 91.2% of 1.71 mg/L in raw seawater sample [14].

Iron in different concentrations (up to 3–4 mg/L and probably reaches 15 mg/L) is present in ground and surface waters [15]. The most significant trouble in membrane working is the scaling and fouling with iron which promotes the propagation of definite kind of microorganisms, gives rise to physical and chemical alterations hindering the water distribution in equipment's and hence they need to clean [16]. So, within few minutes (10–12 min) in concentration of less than 5 mg/L, several processes have been applied in removing iron (II) from groundwater and best and appropriate applied method is the activated carbon media [9,13].

The objectives of this work depend on dual-media filter used for the first time in iron removal from groundwater and it contains *Amphistegina* tests which collected and calcite ooids which fabricated. Also, we are looking forward to discussing of iron removal from groundwater in details in a semi-pilot filtration unit as a pretreatment stage of supposed groundwater desalination plant.

2. Experimental

2.1. Groundwater sample

The groundwater sample was presented from Al-Qurayyat, Jouf Governorate, Kingdom of Saudi Arabia. Physicochemical analyses of the raw groundwater sample are determined in Table 1 by LaMotte spectrophotometer, SMART model, USA origin. The physicochemical properties for definite raw groundwater are the major sources that have a worthy influence in the selection and formulation of the pretreatment process [17]. From Table 1, there are different parameters need to reduce in the pretreatment stage such as SDI (4.83), turbidity (1.24 NTU), total organic carbon (0.87 mg/L) and the main parameter present in our raw groundwater sample is the iron (1.47 mg/L).

2.2. Filtration media

Collecting the *Amphistegina* tests (hard parts or shells) of Foraminifera genus, Fig. 1A, by sieving from the coasts of Mediterranean and Red seas in Egypt in the main size of 1.2 mm with bulk density of 80 lb/ft^3 [10,12]. While, the calcite ooid granules with mesh size varying from 0.5 to 3.0 mm with bulk density of 87 lb/ft^3, Fig. 1B, were made by softening seawater and obviously named the process of cold lime softening at room temperature and adding the hydrated lime to fresh seawater [14,18]. Some ooids were slightly cracked and microphotographed by scanning electron microscope, JEOL JFM 5300 model as shown in Fig. 2. The fractured ooids explained that each sand grain (has a smooth surface) works as nucleus and covered with thin layers of calcite, Fig. 2A. To each other, these layers are parallel, smooth and their thicknesses are uniform. The main constituents of film layers are vertical calcite crystals stacked with each other (side by side). These layers are nearly identical in thickness. But outer layers that are noticed thicker than the inner layers in many inclusions Fig. 2B.

2.3. Semi-pilot filtration unit

The constituents of the semi-pilot filtration unit of groundwater involve *Amphistegina*, fabricated calcite ooids, and *Amphistegina*-ooids dual-media filters, which are explained in detail in Fig. 3. The raw water tank filled by fresh groundwater sample is injected by chlorine dose sufficient to sterilize the groundwater using a chemical dosing pump. A feeding pump takes raw water to the three separate vessels working in parallel; the first and second filters are the vessels involved single-media, and the last vessel contains double (dual) media. The required maximum bed volume to fill the vessel with standard size (7 inches; diameter × 17 inches; height) is 13.2 L. For the first single-media filter; the *Amphistegina* tests volume required for ideal working conditions is 8.6 L with media depth of 11.1 inch [10]. Then, the second single-media filter; the fabricated calcite ooids volume required for ideal working conditions, is 7.92 L with media depth of 10.2 inch [14]. After that, the third filter; has two layers of media includes *Amphistegina* and ooids. The first layer (ooids) is 2.28 L with

Table 1
Physico-chemical analysis of raw groundwater sample

Parameter		Cations, mg/L	
pH	6.8	Na^+	732
Conductivity, μS/cm	3,574	K^+	7.9
Total dissolved solids, mg/L	2,895	Ca^{2+}	187
Total hardness, mg/L	476	Mg^{2+}	103
$SDI_{15\text{-min}}$ (15-min silt density index)	4.83		
Turbidity, NTU	1.24		
Total organic carbon, mg/L	0.87		
Metals, mg/L		**Anions, mg/L**	
Fe	1.47	Cl^-	954
Mn	0.48	HCO_3^-	235
		SO_4^{2-}	326
		NO_3^-	9.59
		SiO_2	11.1

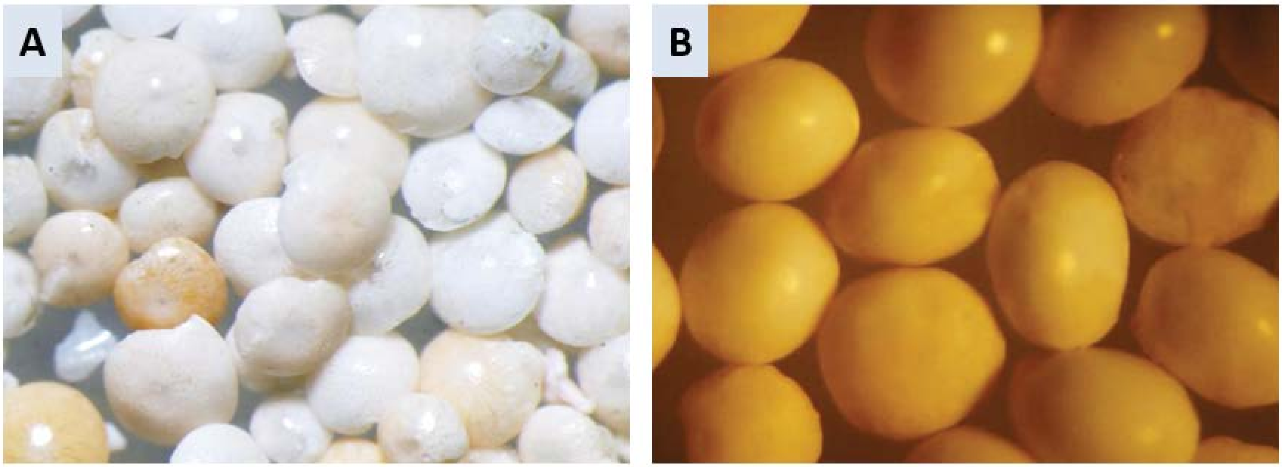


Fig. 1. Pictures of *Amphistegina* tests (A) and fabricated calcite ooids (B) typical sizes, shapes and external appearance.

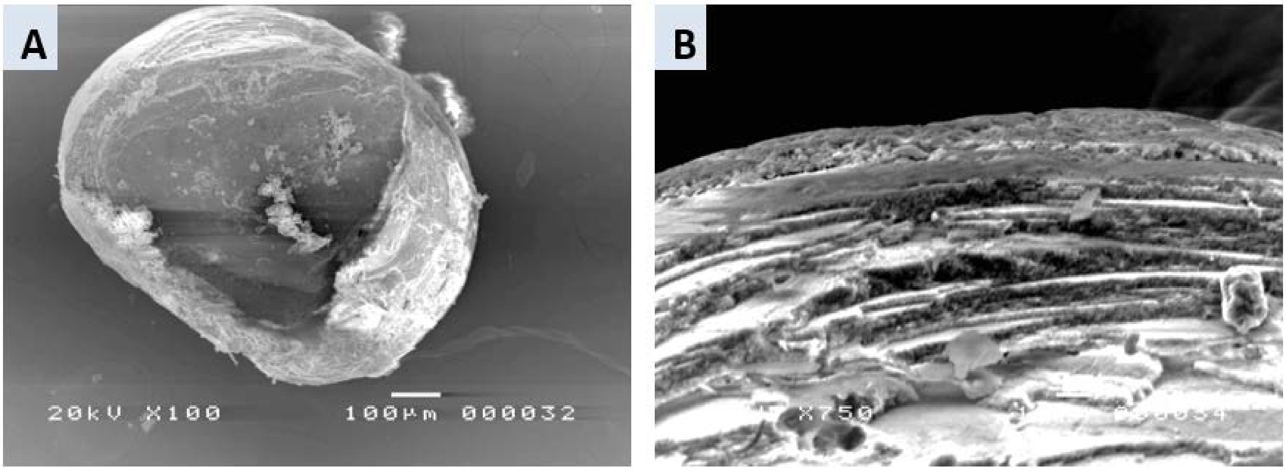


Fig. 2. Scanning electron micrographs of calcite ooids formed through seawater softening process.

media depth of 2.9 inch and the second one (*Amphistegina*) is 5.97 L with media depth of 7.7 inch. And finally, the produced filtrate is passed to the product water tank.

3. Results and discussion

3.1. Chlorine dosages and iron removal

Water disinfection by chlorination technique has been the best, a popular and appropriate method in water treatment (especially groundwater) for a long time. One of the more widely disinfection ways used globally and led to dominance on waterborne diseases is the chlorination process. Two major types of expected chlorine disinfection byproducts are haloacetic acids and halogenated trihalomethanes [19,20]. So, we need to decrease the chlorine dosage in the raw groundwater tank by chlorine dosing pump and depend on media filtration to remove the excess (residual) chlorine from the injection step.

Fig. 4 represents that the excess of iron in groundwater can be removed by chlorine without filtration media but in small concentrations. The raw iron concentration in the groundwater tank (1.47 mg/L) can be removed completely (100%) by increasing the chlorine doses from 0.1 to 1.0 mg/L.

3.2. Effect of filtration media on iron removal

Fig. 5 represents the variations of temperatures (at a lower temperature (293 K) and at higher temperature (313 K)), water pumping speeds from 0.02 to 0.06 m^3/h through the three media filters (ooids, *Amphistegina*, and dual-media filters), and residual iron concentration from blank concentration (1.47 mg/L) in the absence of chlorine. At lower temperature and lower water velocity through media, the ferrous concentration in the raw water tank is 1.47 mg/L, and the residual ferrous concentration becomes 1.35 mg/L after passing through ooids filter; 1.18 mg/L after passing through *Amphistegina* filter and in case of dual-media filter, the residual iron becomes 0.86 mg/L. With increasing the flow rate, the residual iron concentrations reached the biggest values (the quality of media becomes

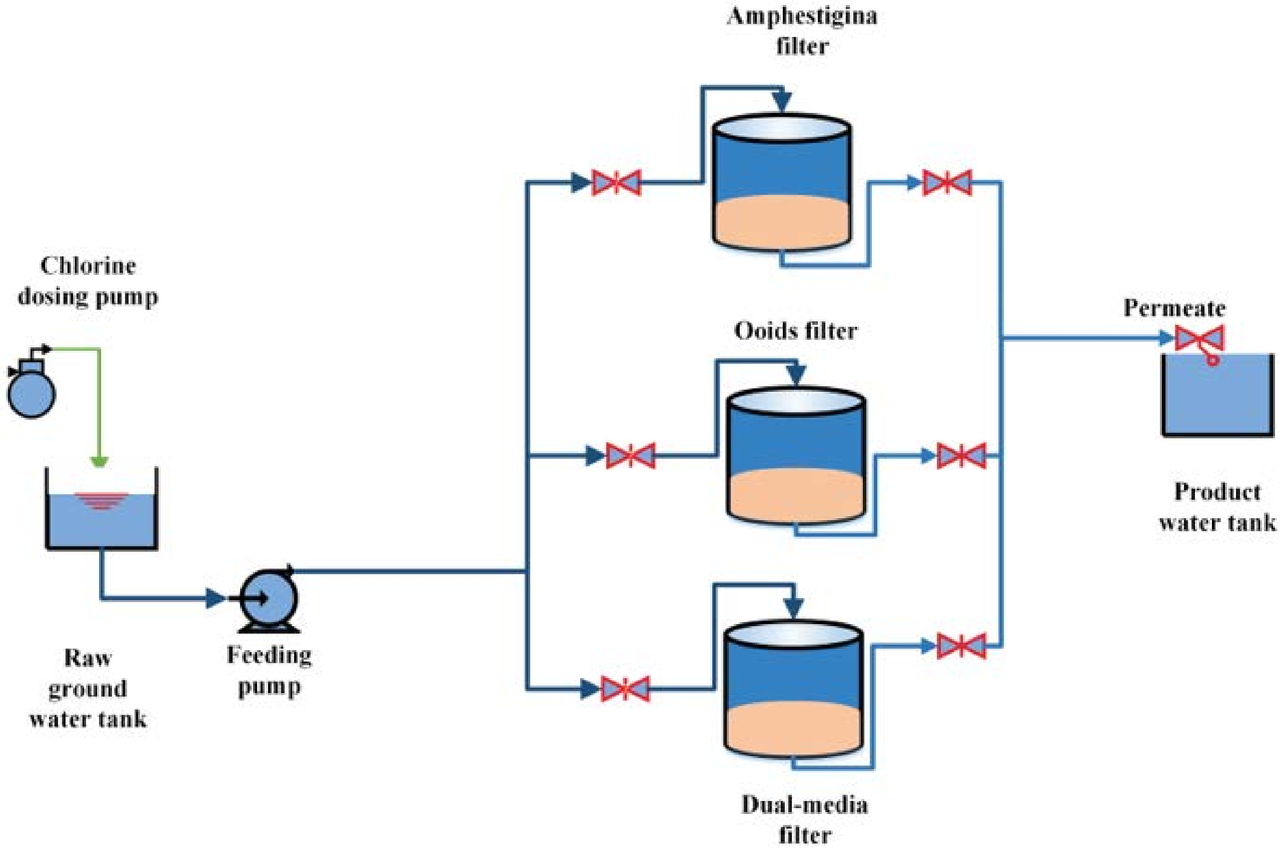


Fig. 3. Schematic diagram of a pretreatment semi-pilot unit of media filtration for groundwater involved dual-media filter.

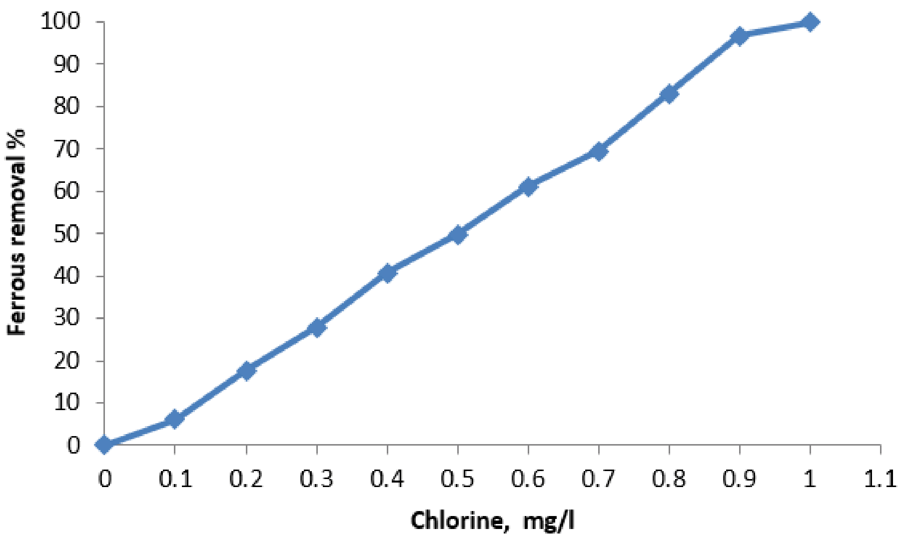


Fig. 4. Variation of chlorine dosages with ferrous removal percentage without filtration media.

less) till the removal value becomes zero in the case of the ooids filter, Fig. 5A.

The ferrous concentration in the raw water tank was 1.47 mg/L at a higher temperature (313 K) and lower water velocity through media. However, the residual ferrous concentration becomes 1.16 mg/L, and after passing through the ooids filter, 0.79 mg/L of ferrous was achieved after passing through *Amphistegina* filter. Then in the case of a dual-media filter, the residual iron becomes 0.38 mg/L, as shown in Fig. 5B. The experiments in current work shows that the removal efficiency of iron concentration at higher temperature is higher than that of lower temperature for all filters,

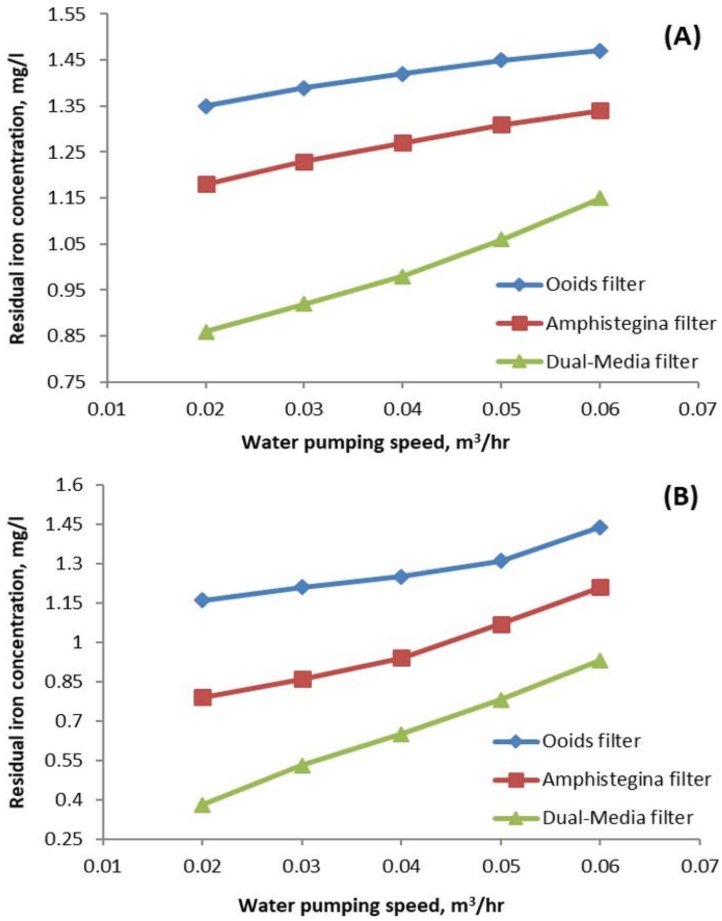


Fig. 5. Variation of different water pumping speeds with residual iron concentrations from iron concentration blank (1.47 mg/L) by different media in the absence of chlorine at 293 K (A) and 313 K (B).

especially in the case of dual-media filter at a lower water speed that reaches 74.15%. While at lower water speed also, but at a lower temperature, the removal efficiency percentage for dual-media filter was 41.5% only.

The lower iron removal in case of higher water flow rate (0.06 m^3/h) such as 36.73% and 21.77% for dual-media filter at higher temperature and lower temperature, respectively, is attributed to that higher filtration leads to shorter filtration cycle which can cause filters to clog and grains permeation from filter vessel was observed through a continuous filtration operation [10].

This behavior of calcite beach sediments (ooids and *Amphistegina*) in removing the iron from groundwater at higher temperatures is attributed to the spontaneous adsorption process that increased with increasing temperature and driving force of adsorption. Also, this reaction during the adsorption reaction increased the randomness at the solid-solution interfaces [18–22].

3.3. Effect of chlorine dosages and filtration media jointly on iron removal

The chlorination process is an oxidation reaction that takes place to ferrous ions forming ferric ions by different oxidants. The best popular chemical oxidants in water treatment techniques are ozone, potassium permanganate, chlorine dioxide, and chlorine. Chlorination is frequent process applied in groundwater systems, and required equipment is very simple, easy, and almost cheap such as chemical dosing pumps [23]. The insoluble formed ferric ions (mainly iron hydroxide complex $Fe(OH)_3$) must be removed by direct media filtration [20,23].

For disinfection and iron removal processes, injection of different dosages of chlorine by dosing pump in groundwater tank followed by different media filters used in this study is represented in Fig. 3. These three media filters (ooids, *Amphistegina*, and dual-media) were used individually to remove the insoluble iron complex (formed by chlorination process) and treat the other soluble part (residual ferrous ions) at two different conditions. The first condition applied is lowering pumping speed to 0.02 m^3/h. and rising temperature to 313 K, as shown in Figs. 6A, 7A, and 8A. The second condition applied in the filtration unit is rising the water feeding pump to 0.06 m^3/h and lowering the temperature to 293 K, as shown in Figs. 6B, 7B and 8B.

From all figures, we conclude that the removal efficiency of residual ferrous ions increased with increasing temperature and decreasing water pumping speed. The calcite beach sediments individually, such as ooids and *Amphistegina*

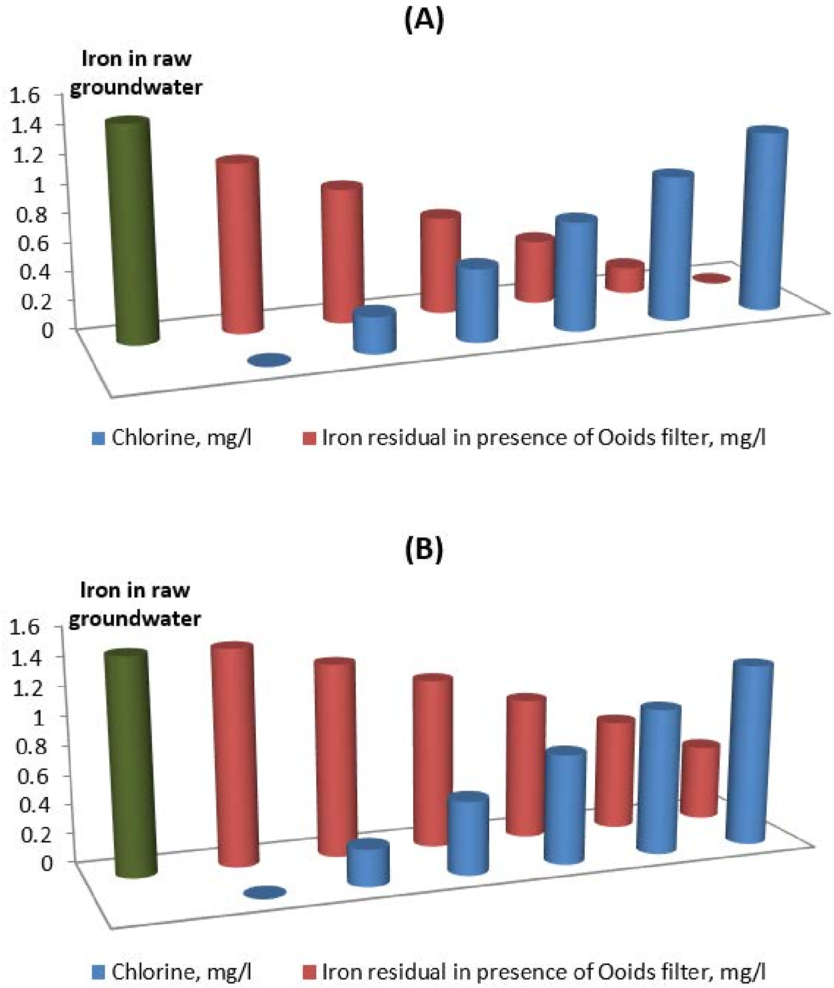


Fig. 6. Effects of chlorine dosages and ooids filter on iron removal from raw groundwater (1.47 mg/L) at; (A) lower pumping speeds (0.02 m^3/h) and higher temperature (313 K) and (B) at higher pumping speeds (0.06 m^3/h) and lower temperature (293 K).

filters [18,21], and in combined such as dual-media filter are suitable for iron removal from groundwater, and the more efficient removal is achieved in dual-media filter.

Fig. 6A represents that the residual iron removal increased from 1.16 mg/L to zero value with increased the chlorine dosage from the absence of chlorine to 1.25 mg/L in the state of the ooids filter. While rising water feeding to 0.06 m^3/hr and lowering the temperature to 293 K as shown in Fig. 6B, the residual iron is still large with 1.25 mg/L chlorine reached to 0.52 mg/L only in case of ooids filter also.

In the case of *Amphistegina* filter, Fig. 7A, we need to 1.0 mg/L of chlorine to remove all residual ferrous concentration (zero iron) at lower pumping speeds (0.02 m^3/h) and higher temperature (313 K), but from Fig. 7B, the rising of water pumping speeds (0.06 m^3/h) and lowering temperature (293 K), the minimum residual iron is 0.4 mg/L reached 1.25 mg/L of chlorine.

The best results are observed in the case of dual-media filters, as shown in Fig. 8. We need only less than 0.5 mg/L of chlorine to remove all residual ferrous concentration (100% removal) in the presence of a dual-media filter at low pumping speed (0.02 m^3/h) and high temperature (313 K), as shown in Fig. 8A. While increasing water pumping velocity to 0.06 m^3/h and lowering the temperature to 293 K, the removal of the ferrous ion (100% removal) needs to 1.0 mg/L of chlorine in the presence of a dual-media filter, as shown in Fig. 8B.

4. Conclusion

In this paper, Al-Qurayyat, Jouf Governorate, Kingdom of Saudi Arabia is the region of our examined groundwater sample. Different materials used in pretreatment stage were applied on groundwater treatment to remove the ferrous ions such as ooids, *Amphistegina*, and jointed ooids-*Amphistegina* dual-media filters. We examined the effects of individual chlorine and media filters and the combined effects of chlorine and media filters on iron removal. We observed that dual-media filter is more effective in iron removal from groundwater than other mono-media filters in the same conditions. There are expected disinfection byproducts taken place by chlorine injection in high concentrations. But with moderate chlorine injection in raw groundwater tank and then fed to media filtration

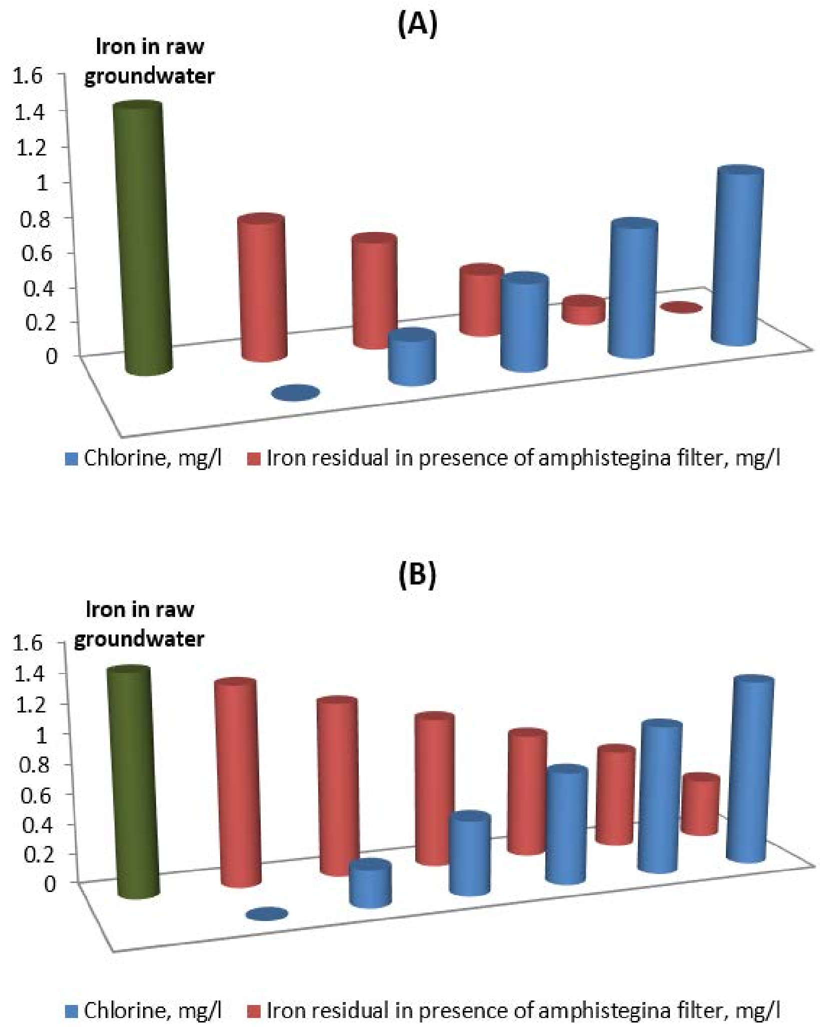
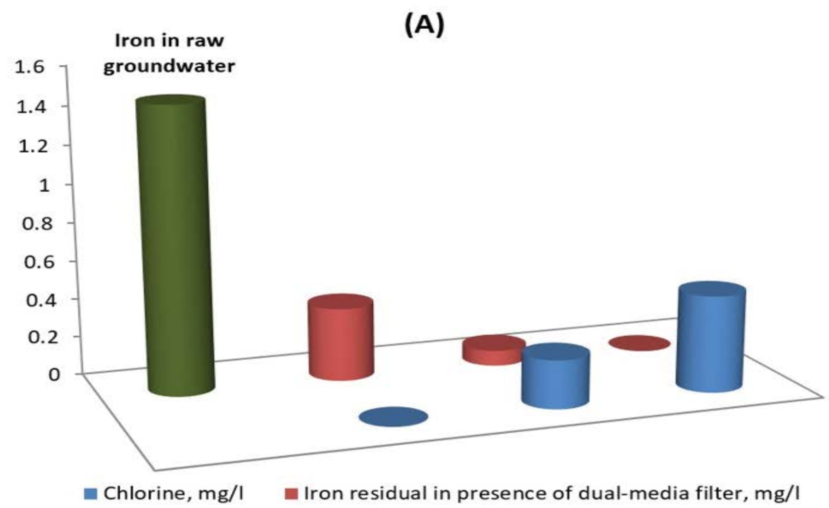


Fig. 7. Effects of chlorine dosages and *Amphistegina* filter on iron removal from raw groundwater (1.47 mg/L) at; (A) lower pumping speeds (0.02 m^3/h) and higher temperature (313 K) and (B) at higher pumping speeds (0.06 m^3/h) and lower temperature (293 K).



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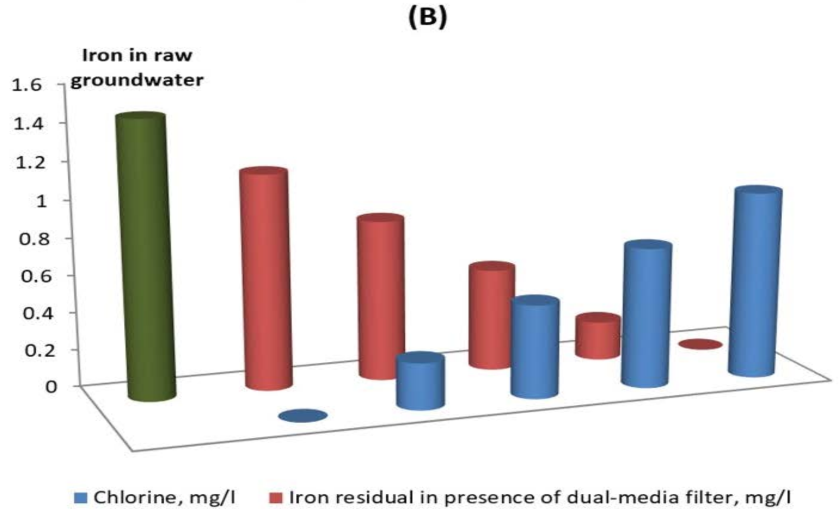

Fig. 8. Effects of chlorine dosages and dual-media filter on iron removal from raw groundwater (1.47 mg/L) at; (A) lower pumping speeds (0.02 m^3/h) and higher temperature (313 K) and (B) at higher pumping speeds (0.06 m^3/h) and lower temperature (293 K).

processes, especially dual-media filter, it gives the best, save, and appropriate filtrated groundwater free of ferrous ions. According to our achieved results in current paper, this filtrate is suitable for groundwater desalination plant.

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