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Pretreatment for Brackish Water Reverse Osmosis of Desalination Plants by Dual-Media Filter

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Abstract
By sieving the Amphistegina tests of average size of 1.2 mm and accumulated from different costs of Red and Mediterranean seas in Egypt and a definite calcite Ooids of mesh size from 0.5–3.0 mm that formed inside a semi–pilot of seawater–softening unit. Recently, we used the dual–media (DM) filter that consisting of Amphistegina tests and fabricated calcite Ooids in removing ionic iron from groundwater. Thereafter, for the first time we have used that recent filtration dual–media as pretreatment technique for brackish water reverse osmosis stage in desalination plants and raw brackish water samples are brought from Al–Qurayyat Governorate, Jouf, Kingdom of Saudi Arabia. Dual filtration media demonstrated an excellent feed water quality improvement producing filtrate of accepted quality to feeding brackish water reverse osmosis (BWRO) membranes at optimum operating conditions of temperature (40 ^{o}C) and flow rate (20 l/min). In presence of polyaluminum chloride coagulant, the better silt density index (SDI) of produced filtrate (SDI <3), turbidity of less than 0.1 NTU, total organic carbon (TOC) reducing of higher value reached to 98.6% and the highest value noticed by DM filter in iron removal reached to 100 % in presence of injection of chlorine in the feed water tank.

Keywords: Water treatment; Brackish water; Filtration; Calcite ooids; Amphistegina test; Dual-media filter

1. Introduction

From the brackish waters, groundwater is a major constituent besides the waters of swamps and lakes, while the Kingdom of Saudi Arabia does not have lakes or swamps, but it depends mainly on groundwater. Brackish water is any source of water with total dissolved solids content (TDS) between 500 to 10,000 mg/l [1, 2]. This brackish water cannot be consumed directly due to its high salinity. According to the World Health Organization (WHO), the accepted drinking water has a salinity of less than 500 mg/l [3].

Groundwater has a wide variety of pollutants that we must treat before entering the BWRO membrane such as turbidity, salinity, organic matter, biological and mineral contents to avoid clogging and fouling. Therefore, pretreatment techniques are necessary to avoid damage of membrane and they are important branch in designing the desalination plants to improve the performance of reverse osmosis (RO) membrane and to increase the life time of membrane in desalination plants [4,5]. In a previous work, it was known that scale and fouling are the abundant critical problems in operating of RO membrane, it could be related to operational problems. So, the *Amphistegina* tests showed high effectiveness in removing suspended solids from feed water and produced the qualified permeability for RO membrane feed. The resulting filtrate has better SDI (<3), lower turbidity (<0.2 NTU), and reduced TOC (97.1%) [6–9]. Also, the fabricated *calcite Ooids* in the pretreatment stage were used as new filter media for desalination plant. The filtrate produced has higher turbidity reduction (89.4%), best SDI (2.85), higher TOC reduction (66.1%) increased to 95.7% after the activated carbon (AC) filter [10]. And recently from groundwater samples which brought from Al–Qurayyat Governorate, Jouf, Kingdom of Saudi Arabia, we success to remove iron completely by new dual–media (DM) filter [11].

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Our previous experience shows that using DM filters, higher removal efficiency of iron was achieved at optimum operating condition of temperature (40 °C) and flow rate (20 l/min) [11]. So, in current article, all experimental work was utilized at temperature (40 °C) and flow rate (20 l/min)

Our targets in this research depend on the application for the first time of the recent dual–(*Ooids–Amphistegina*) filter for the groundwater desalination plant in the pretreatment stage instead of the traditional techniques and compared to the individual techniques (mono–media). The comparison occurs between *Ooids*, *Amphistegina* and DM filters to optimize and choice the best adjectives such as SDI, turbidity, TOC and iron removal and to study the operating conditions such as the bed expansion percentage and the service and backwash flow rate.

2. Experimental

2.1. Groundwater sampling

The sampling location is Al–Qurayyat Governorate, Jouf, Kingdom of Saudi Arabia, in this research, this region depends mainly on groundwater as a major source of life in general and for drinking and agriculture in particular. The raw groundwater sample had analyzed as shown in the Table 1 using LaMotte spectrophotometer, SMART model, USA origin. There are different constituents of the sample of raw groundwater such as iron (1.58 mg/l), TOC (0.89 mg/l), SDI (4.89 mg/l) and turbidity (1.27 mg/l). These high–concentration constituents must be removed in the pretreatment stage before reaching the final treatment stage (reverse osmosis unit), which is affected quickly or cumulatively, and is a relatively more expensive stage [12].

Table 1. Physicochemical analysis of raw groundwater sample

Parameter		Anions, mg/l		Cations, mg/l		Metals, mg/l	
pH	6.9	Cl^-	977	Na^+	748	Fe	1.58
Conductivity, µS/cm	3687	HCO_3^-	242	K^+	7.92	Mn	0.52
TDS, mg/l	2962	SO_4^{2-}	331	Ca^{2+}	193		
Total hardness, mg/l	463	NO_3^-	9.63	Mg^{2+}	107		
SDI_{15min} (15-min Silt Density Index)	4.89	SiO_2	11.3				
Turbidity, NTU	1.27						
TOC, mg/l	0.89						

2.2. Dual-media role

There are two main constituents of DM filter. From the foraminifera genus, the hard and shells of *Amphistegina* tests is the first constituent [6] which collected from Red and Mediterranean seas coasts in Egypt [11], and the fabricated calcite *Ooids* [10] is the second one in our DM filter. From Figure 1, *Amphistegina–Ooids* DM are of the standard main sizes 1.2 and 0.5–3.0 mm, respectively [11]. The standard volume of media required to fill the filter vessel of size of 7 inches (diameter) × 17 inches; height is 13.2 liter. There are two layers of *Ooids* and *Amphistegina* media in the DM filter have a depth of 7.7 and 2.9 inch and quantity of 5.97 and 2.28 L, respectively. This media is sufficient to filtrate the raw water in ideal working conditions [11]. This DM filter is an alternative to the multi–layer filter, carbon filter and chlorine injection in the initial treatment stage. It is considered a suitable alternative to perform their roles or some of their roles combined.

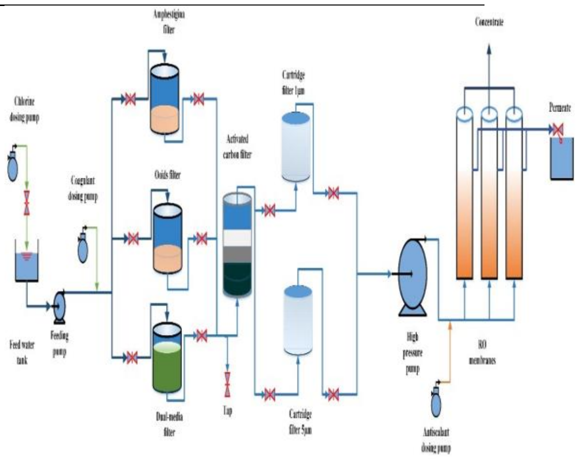

Figure 1: Schematic diagram of a pretreatment media filtration stage for a groundwater desalination plant involved DM filter

2.3. Membrane type

One spiral wound polyamide filmtec membrane its model is FILMTEC[th] BW30–4040 in stainless steel housing needed a high pressure pump, its specifications; 6 m^3/h, 17 bar max, kw 15, IP 55, class F and stainless steel 304, to supplied the groundwater filtrate. The FILMTEC™ brackish water reverse osmosis membrane has almost permeated flow rate of 9.1 m^3/d and salt rejection of 99.5 % [13].

2.4. Scale inhibitor

To prevent or control scaling on membrane surface, different scale inhibitors can be used such as polyacrylates, organophosphonates and sodium hexametaphosphate. Organophosphonates are higher operative and more indeclinable than hexametaphosphate and acting as anti–fouling of insoluble iron, while polyacrylates that have high molecular weight are used in general for silica scale reducing [14]. A commercial permatreat 510 antiscalant developed for groundwater which is a mixture of phosphonates and polyacrylates and injected by chemical dosing pump of 5 liters and 7 bars. This antiscalant is effective for calcium salts precipitation such as sulfate, carbonate and fluoride and also for iron fouling reducing [15].

2.5. Coagulant

The lower the turbidity, the less likely the membrane will be fouled. Reducing turbidity is a desirable target using media filtration alone and with the help of a coagulant [16]. Even without adding coagulant, all media filtrations have definite turbidity reduction. While when adding coagulant under specific conditions, turbidity gradually decreases [10]. The commercial poly–aluminum chloride (PAC) is the more efficient coagulant for water treatment over conventional coagulants. This can be attributed to the low dosage requirement, shorter flocculation time, smaller amount of sludge, and low aluminum residual in treated water. PAC also works at all turbidity levels and can cause a minimum drop in pH [17]. When adding commercial PAC to help filtration media in reducing turbidity and suspended solids from freshwater, the effective dose is 1.6 mg/l with the best filtrate [16]. This coagulant was injected by chemical dosing pump of 5 liters and 7 bars to the makeup water line.

3. Results and discussion

3.1. Effect of chlorine dosages followed by media filtration jointly for iron removing

Chlorine is the common and effective material used for sterilizing the groundwater and injected to the tank of raw groundwater using chemical dosing pump. Also, it used for iron reduction purpose [11]. But we must take precautions in adjusting or reducing the dose so as not to reach byproducts such as haloacetic acids and halogenated trihalomethanes that have major side effects on human health [18,19]. According to the technical bulletin of de–chlorinating feed–water for Filmtec membranes, the premature membrane failure will have caused in presence of free chlorine. FilmTec recommends removing residual free chlorine (not exceed 0.1 ppm) by pretreatment prior to membrane exposure [20].

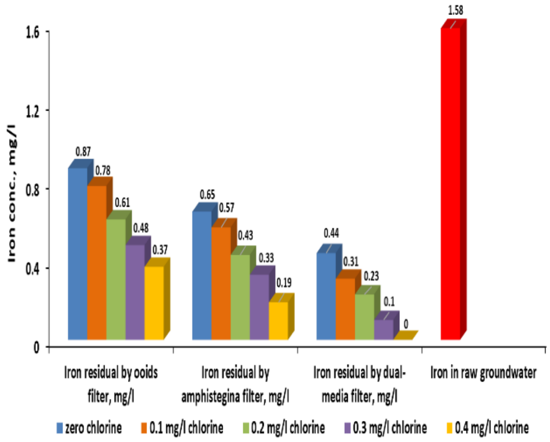

Figure 2: Effects of chlorine dosages followed by different–media filters on iron removal from raw groundwater (1.58 mg/l) at pumping speeds (20 l/min.) and temperature (40 °C)

3.2. Effect of different-media filters followed by AC filter on TOC reduction

AC filter is mainly used for adsorption of organic and inorganic compounds from water and the organic compounds are more commonly adsorbed on activated carbon filter than inorganic compounds [21–23]. Large particles in the groundwater are likely to be effectively collected by the coagulant aid and captured by the media–filter and cartridge micron filter [10]. The most likely explanation for the ability of mono– or dual–media filter media surfaces to adsorb TOC from groundwater is the differences in the properties of mineral surface properties between calcite (*Ooids* and *Amphistegina*) and quartz (sand) and there are many differences in the electron densities between them [24]. Then, the common feature of these electron–dense metals is the asymmetric distribution of electrons in the electron shell [25]. The polarization (electric dipole) takes place by separation of negative and positive charges and van der Waals bonds is established by attraction of polarized structures and other dipoles. The organic particle contaminants that have polar molecules with partially charged ends are attracted to others. Prospective dipoles that linked to mineral dipoles are proteins or hydrogen bonds with function groups such as carboxyl and hydroxyl groups [26]. Thereafter, more and further investigations of adsorption reasons may be takes place for *Ooids* and *Amphistegina* with organic matters and to increasing the adsorption behavior.

The TOC content in the feed groundwater tank is 0.89 mg/l was needed to reduced. At operating conditions of 40 °C and 20 l/min, the feed groundwater passes through the individual media filter vessel then followed by AC filter. Figure 3 represents that the TOC reduction reached to 52.1, 65.5, 87.3 and 84.7 % by *Ooids*, *Amphistegina*, DM and AC filters, respectively. While in case of *Ooids* filter followed by AC filter and *Amphistegina* filter followed by AC filter, the TOC reduction reached to 95.1 and 97 %, respectively. Finally, the best TOC reduction reached to 100 % by DM filter followed by AC filter.

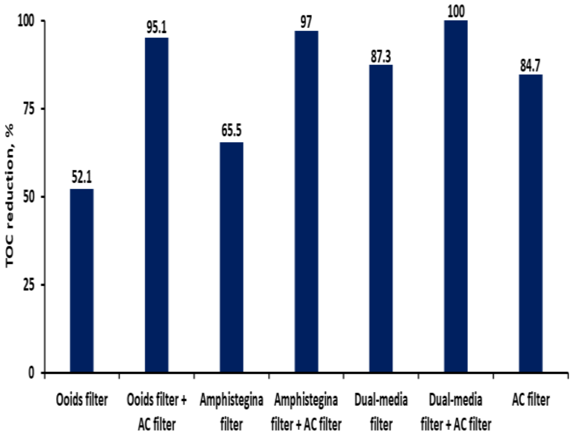

Figure 3: Effect of different–media filters followed by AC filter on TOC reduction from groundwater (0.89 mg/l) at pumping speeds (20 l/min.) and temperature (40 °C)

3.3. Silt density index (SDI)

There are many limiting parameters of groundwater filtrate must be taken in consideration through design and RO desalination plants operation, the most important of which is the silt density index. The tolerable SDI value of filtrate is less than 4 [27]; while in another study, the filtrate with the acceptable SDI value is less than 3 [28,29]. The reduction of SDI value by pretreatment media filters of water desalination plant is very necessary to prevent membrane fouling [27,30] and the calcite beach sediments gave the best SDI reading (less than 3.0) when compared with other different pretreatment techniques [6,31]. The operation in presence of PAC coagulant, cartridge micron filters (1 and 5 micron) and at 20 l/min and 40 °C, the DM filter was compared to different filtration media.

Figure 4 represents that 15–min SDI readings at optimum conditions in absence of PAC near 5.0 value for raw groundwater and it decreased a little in adding PAC reached to 3.85. But in case of *Ooids* and *Amphistegina* filter without PAC, the SDI readings were 3.86 and 3.52, and they decreased to 2.92 and 2.76, respectively, in the presence of PAC. While in case of DM filter, the SDI value decreased to less than 3.0 without PAC adding and gave the best SDI reading reached to 2.35 in presence of PAC.

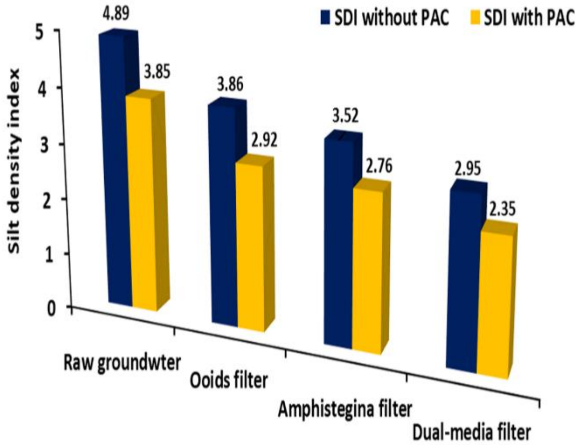

Figure 4: Variations of SDI_{15} of different pretreatment media filters with and without PAC

3.4. Turbidity

One of the important factors in the quality of groundwater filtrate produced for feeding a desalination plant. The lower the turbidity value (less than 1.0 NTU), the less chance of fouling the RO membrane and the filtration media have the main role in turbidity reduction even without or with coagulant adding and micron filter [16]. At the optimum operating conditions, in presence of PAC coagulant, micron filters and at 40 °C and 20 l/min, *Ooids*, *Amphistegina* and DM filters are compared with each other.

Figure 5 shows that turbidity in raw groundwater (1.27 NTU) was reduced to 0.92 NTU with PAC adding only. But in case of *Ooids* filter, the turbidity in filtrate was 0.95 and 0.61 NTU without and with PAC adding, respectively. While, the *Amphistegina* filter produced filtrate with turbidity of 0.77 and 0.46 NTU in absence and presence of coagulant, respectively. Finally, the best turbidity readings appeared in case of DM filter that reduced to 0.35 NTU in absence of coagulant and the smallest turbidity value in presence of PAC was 0.05 NTU.

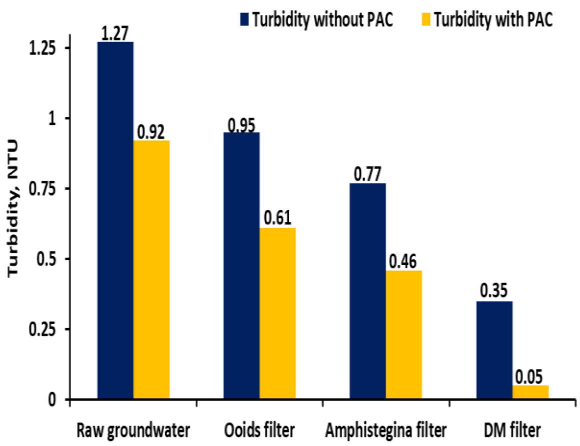

Figure 5: Variations of turbidity of different pretreatment media filters with and without PAC

3.5. Service and backwash flow rates and bed expansion percentage

The main constituents for *calcite Ooids* and *Amphistegina* tests are the calcite with a specific gravity of calcite is 2.71 gm/cc and a specific gravity of quartz (sand) is 2.65 gm/cc. therefore, our DM has a tangible weight and the calcite is heavier. Consequently, the bed expansion percentage, and service and backwash flowrates are the essential influencing operating factors and the media weight is the more effective parameter in operating [6]. The filter cycle (full service period), when the media granules are saturated by suspended solids and turbidity, the filter became clogged it required to backwashed immediately using multiple flow rate of groundwater. In backwash operation, the bed expansion is considered as the most important factor in cleaning the media and returning it to its original efficiency [10,32].

From Figure 6A, at temperature of 40 °C, *Ooids* filter had service flow rate of 11.1 l/min and *Amphistegina* filter of 14.5 l/min (higher by 23.45%). This is due to the chamberlets or void network that occurred in the inner structure of *Amphistegina* tests. This network reduced the total weight and hence, their float is increased [33]. While, in case of DM filter, the service flow rate is 13.3 l/min (close to *Amphistegina* filter by 8.3 %). This is due to the media contains a higher weight of *Amphistegina* tests (5.97 l) than *Ooids* (2.28 l), so the DM filter produced a valuable filtrate quantity, it considered in the middle flow rate point but still close to *Amphistegina* filter.

Figure 6B represents that *Ooids* filter requires a backwash flow rate of about six and a half times the service flow rate (71.8 l/min) and the *Amphistegina* filter needs 85.3 l/min of backwash flow rate (nearly six times the service flow rate). While, in case of DM filter, the saturated media required a backwash flow rate of 5.6 times only of the service flow rate and it has a less backwash flow rate value.

Finally, with increasing the bed expansion percentage inside the filter vessel through the backwash process, the media rises to the maximum possible height, sufficient for easy water flow and cleaning of media granules particles which helps to increase the operating lifetime. Therefore, Figure 6C represents that *Ooids* filter has lower bed expansion percent (38.2 %) and the DM and *Amphistegina* filters have close expansion percentage values to each other.

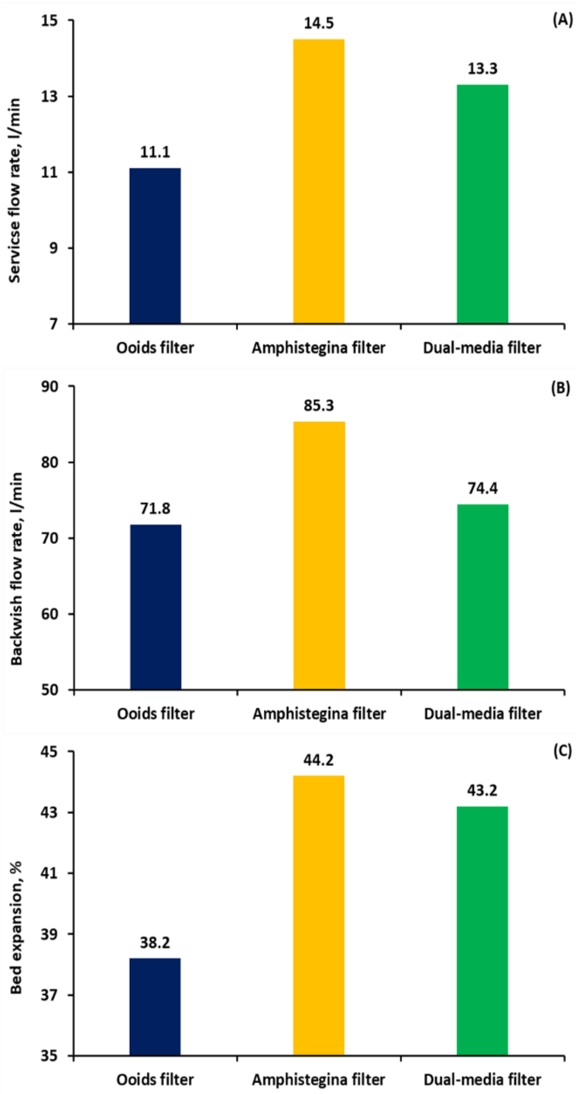

Figure 6: Variations of ooids, Amphistegina and dual-media filters with: (A) service flow rate; (B) backwash flow rate and (C) bed expansion percentage at 40 °C.

4. Conclusion

The pretreatment stage by filtration media is very important technique in the brackish desalination plants and required for the integrity of osmotic membranes. Here, the DM filter (calcite *Ooids–Amphistegina* tests) was used for the first time and it was suitable for groundwater in Al–Qurayyat Governorate, Jouf, Kingdom of Saudi Arabia. The produced filtrate was qualified for feeding the reverse membrane of brackish water desalination plant at optimum operating conditions (temperature of 40 °C, flow rate of 20 l/min). Also, the produced filtrate in presence of PAC and micron filter has the best SDI, less turbidity, TOC reduction and better iron removal percentage. Finally, we had studied the best and appropriate working conditions such as service and backwash flow rates and bed expansion percentage by DM filter and it met the RO requirements.

Conflicts of interest

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

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