Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2014.944219

55 (2015) 718–730
July

Taylor & Francis
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New pretreatment media filtration for SWRO membranes of desalination plants

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Received 9 April 2013; Accepted 30 June 2014

ABSTRACT

It is well known that seawater is contaminated with suspended solids, colloidal particles, and organic matters. Therefore, unless the contaminants are removed from the feed water prior reverse osmosis (RO) membrane, they will cause a severe membrane fouling problem by deposition on its surface. It is also known that the Foraminifera genus, *Amphistegina*, are found on the coasts of the Red and the Mediterranean Seas in very large quantities. Therefore, our attention in this paper is to evaluate the applicability of *Amphistegina* tests as new pretreatment media filtration compared with conventional sand filtration technique used for seawater desalination plants. In this work, *Amphistegina* tests were separated directly by sieving from fresh beach sediments with mesh size 1.0–1.5 mm. According to the operating conditions for each media filtration system, the performance of the two different systems has been evaluated. From studying the filtrate quality parameters, both media filtration systems demonstrated a similar performance in removing particulates from the feed seawater and produced permeates of acceptable quality for feeding RO systems at different temperatures of 20, 30, and 40˚C and different flow rates of 20, 40, and 60 l/min. The optimum conditions were obtained using 20 l/min and 40˚C, and the amphistegina filter produced water with much better quality compared with that produced by sand filter. This study is based on a semi-pilot desalination unit located in the Egyptian Petroleum Research Institute (EPRI).

Keywords: Seawater desalination; Reverse osmosis; Filtration; *Amphistegina* tests; Pretreatment; Membrane

1. Introduction

Seawater pretreatment is the first stage of reverse osmosis (RO) membrane desalination plant. The main purpose of the pretreatment system is to remove foulants contained in the seawater and to prevent their accumulation on the surface of reverse osmosis (SWRO) membrane. The content and nature of foulants, contained in the seawater, depend on the type

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Presented at the 13th International Conference on Environmental Science and Technology (CEST 2013) 5–7 September 2013, Athens, Greece

and location of the desalination plant intake. Classically, seawater foulants were removed by different pretreatment conditioning processes such as break-point chlorination, acid addition, in-line coagulation, and addition of a flocculation aid followed by a conventional single- or double-stage sand filtration [1]. The first factor that affects the performance of RO desalination processes is the quality of raw water and the effectiveness of the pre-treatment procedures [2]. Traditionally, two types of pretreatment systems are used to prevent seawater reverse osmosis membranes fouling: conventional granular media filtration and membrane filtration. While granular media filtration is the most widely used in seawater pretreatment technology [3], the common two types of media used in granular bed filters are sand and anthracite coal. These may be mainly used alone or in dual media combinations. Furthermore, granular filters can be made from a variety of natural materials, depending on the origin of these materials and they can have very different shapes, sizes, and compositions [4].

Many SWRO systems are fed using water of beach wells with low suspended solids. In such cases, it is possible to achieve SDI_{15} (15 min SDI) below 3 [5] using sand filtration without coagulant, or even simple 5 μm cartridge filters. Due to plant size needing, onshore beach wells are used with less frequency and SWRO plants fed directly from open seawater intakes [6]. The flow rates of rapid sand filtration, which ranging between 5 and 30 m^3h^{-1}, is physically considered a high technique to remove all suspended solids larger than 0.35 mm from water by size exclusion and adsorption processes. On the other hand, physically, slow sand filtration with flow rates that are ranging between 0.1 and 0.2 m^3h^{-1}, have a high treatment for all suspended solids [7–10]. It is found that when the feed flow rate increases, the permeate concentration decreases [11,12]. In addition, there is an exponentially increase in the permeation flux when the feed temperature increases [12,13].

The major reason for flux decline during long time runs is the scale formation and the addition of some chemicals (acid and alkali) in definite time to the feed water that may be prospected as the first solution for online cleaning and flux recovery for desalination plants [14]. RO membrane fouling is defined as external/internal contamination and the nature of fouling is strongly dependent on feed water contaminants contents (e.g. high total dissolved solids, particulates, and colloidal contaminants) [15]. Sand and dual media filters as common pretreatment techniques are used to remove suspended solids. Usually, over 90% of seawater particulate foulants are larger than 1 μm [16]. For successful pretreatment, an silt density index (SDI) of less than 4.0 is appropriate for the hollow fine fiber membranes and less than 5.0 for the spiral-wound (SW) membranes [17]. Also, total organic carbon (TOC) is another important parameter in the pretreatment process and has a critical influence on fouling; this parameter is related to the adsorption of organic matters on the surface of RO membrane, which may cause flux loss and irreversible fouling and the pretreatment should be considered when TOC exceeds 3.0 mg/l [18].

The conditions at the Egyptian coasts on Red and Mediterranean Seas are suitable for flourishing the micro-organisms of the Foraminifera genus *Amphistegina* to flourish and reproduce at rapid rates. Consequently, they are available in large quantities along the Egyptian coast lines [19,20].

The presents study depends on sediment samples that were collected from Marsa Matrouh on the southern coast of the Mediterranean Sea. The abundance of the *Amphistegina* in these areas reaches 60% of the *Foraminifera* [21]. The internal structure of the *Amphistegina* tests is complicated and contains numerous void cavities or chambers, which in turn divided are into "chamberlets". These cavities are interconnected and are usually inhibited by symbiotic micro-organisms, such as diatoms or dinoflagellates, which live in mutualistic relationship with the *Amphistegina* protoplasm [22]. The high expenses of sand transportation used in media filtration raised the needs for new materials suitable, available, and equal or more efficient in the local environment of desalination plants other than sand media. Therefore, the major objective of this study is to investigate the applicability of the *Amphistegina* tests (shells or hard parts) instead of sand media filtration as a new pretreatment of seawater desalination. The comparison between them takes place in a single media filter to enhance the required filtrate quality which is the most required criteria in seawater desalination unit.

2. Materials and methods

2.1. Feed water

The raw seawater was fed to semi-pilot unit which was obtained from an open intake in the Mediterranean Sea in Marsa Matrouh city. The unit was set up at the Egyptian Petroleum Research Institute (EPRI). The physicochemical analysis of the raw seawater is shown in Table 1, and may be observed that total dissolved solids (TDS) and TOC are 38,700 and 2.6 mg/l, respectively. It is also important to note that the turbidity is close to 2 NTU. In addition, the SDI and Fe values of the raw seawater are higher than that of the membrane tolerable limits.

Table 1
Physicochemical analysis of raw seawater

Parameters		Cations, mg/l		Anions, mg/l		Trace elements, mg/l	
pH	7.7	Na^+	12,245	Cl^-	22,078	Zn	0.25
Conductivity, μS/cm	48.5×10^3	K^+	448	HCO_3^-	217	Cu	0.52
Total dissolved solids (TDS), mg/l	38,700	Ca^{2+}	635	SO_4^{2-}	1,042	B	6.8
Total hardness, mg/l	7,350	Mg^{2+}	1,394	NO_3^-	2.64	Fe	1.65
Salinity, mg/l	35,180			S^{2-}	2,935	Mn	0.75
SDI_{15min}[a]	6.2						
Total suspended solid (TSS), mg/l	11.8						
Turbidity, NTU	1.83						
Total organic carbon (TOC), mg/l	2.6						

[a]15-min silt density index.

2.2. Filter beds

The granular bed filtration applied in this unit was based on a single media filter. Therefore, both sand and amphistegina were used as a filter material in separated vessels operating in parallel, while sand (or amphistegina) and AC materials were used in separated vessels operating successively. In each vessel, the maximum bed capacity, which required to be filled, was 13.2 l and the bed filled in all vessels of sand, amphistegina, and AC were 6.6, 8.6, and 6.6 l, respectively. The characteristics of filter media sand [23], activated carbon (AC) [24], and amphistegina are reported in Table 2. The composition of *Amphistegina* test is mainly $CaCO_3$ with traces of $MgCO_3$, where the test size range is 1.0–1.5 mm ($n = 1{,}000$ tests) and the main size is 1.2 mm [22]. The *Amphistegina* test is coarsely perforate, lamellar, and flattened lenticular and it is often slightly contorted, biconvex, dorsoconvex, or ventroconvex. The peripheral outline is smooth or slightly lobulate and peripheral margins are acute and distinctly imperforate. The filter media used in our semi-pilot unit for the pretreatment of seawater are depicted in Fig. 1.

2.3. Coagulant

Many of coagulant types were used in this study and the commercial polyaluminum chloride (PAC) was found to be more efficient for removing particulates from raw seawater. The main specifications of the used coagulant were summarized in Table 3.

2.4. Semi-pilot RO unit

A semi-pilot RO desalination unit located at EPRI was designed according to the schematic diagram in Fig. 2 to meet the objectives of this study. Therefore, the RO membrane was designed to be capable of producing about 19.4 l/min and the unit consists of a feed and product water tanks (60 l). The chemical pretreatments to the make-up water line were included in the injection of the polyaluminum chloride as a coagulant

Table 2
Characterization of pretreatment media

Parameter	Media		
	Sand	*Amphistegina*	Activated carbon
Particle size range, mm	0.4–1.25	0.5–1.3	0.6–1.35
Effective size, mm	0.45–0.55	0.8–1.2	0.55–0.75
Bulk density, lbs./Ft^3	100	80	31
Bed depth, inch	18–30	22–32	26–30
Freeboard of bed depth, %	50	35	50
Backwash flow rate, gpm/ft^2	15–20	10–18	10–12
Backwash bed expansion, %	20	20–40	30–40
Service flow rate, gpm/ft^2	1.5–2	2–3.5	5

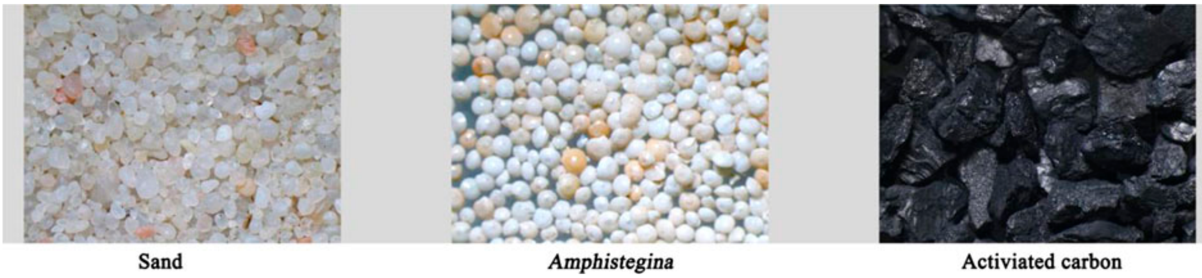

Fig. 1. Photomicrographs of filter media used in the vessels.

Table 3
Specifications of polyaluminum chloride (PAC) coagulant

Parameter	Value
Density at 20℃, g/cm^3	1.28
Al_2O_3%, w/w	13.7
Basicity, %	36
pH (diluted to 50%)	2.2

to support the essential media filtration, and H_2SO_4 was used as an antiscalant to maintain the pH reading at a constant value (chemical feeding by dosing pump, 5 l/7 bar). One feeding water pump (stainless steel 304, 20–60 l/min, and 5 bar max) was used to supply water from feed water tank to each filter vessel, as well as to provide the water necessary for filter backwashing. The coagulated seawater flows to a pair of filter vessels operating successively; these vessels were constructed of a fiberglass reinforced polyester resin for standard water conditioning use with a specific size (diameter 7.0 inches and height 17inches), maximum operating pressure 150 psi, maximum operating temperature 49℃, and full-bed capacity 13.2 l. The top opening of this vessel is 2½ inches. In our semi-pilot desalination unit, the single media vessel had filtration media (sand or Amphistegina), where the selected effective size is typically 0.45–0.55 mm in case of sand media and 1.0–1.5 mm in case of Amphistegina. The mono media filter vessel was followed by a granular activated carbon (GAC) filter vessel with the same mechanical and operating specifications. The required bed capacity for each vessel in liters is 6.6 sand and 8.6 amphistegina in case of mono-media filter; while, it is 6.6 in case of GAC filter vessel as shown in Table 2. These vessels were manually controlled and followed by one cartridge filter (5μ or 1μ). The service flow rates of filtration were 20, 40, and 60 l/min at 20, 30, and 40℃ during normal operating conditions. Also, it is shown from the used media that the operating conditions for lpm/ft^2 are 6–8 and 8–14 for sand and amphistegina filters, respectively.

The high pressure pump (stainless steel 304, 6 m^3/h and 56 bar max) supplies the filtrate to the housing, which is a single membrane pressure vessel of the RO unit and contains a one polyamide thin-film composite membrane (Filmtec SW30HR LE-400 seawater reverse osmosis membrane, SW type) [25]. From Table 4, the membrane nominal active surface area is 37 m^2; its permeate flow rate is 28 m^3/d (19.4 l/min) and the stabilized salt rejection is 99.75%. Two flow meters were connected to measure the fed and permeated seawater of the RO unit. Finally, the whole RO plant was controlled by electrical control panel.

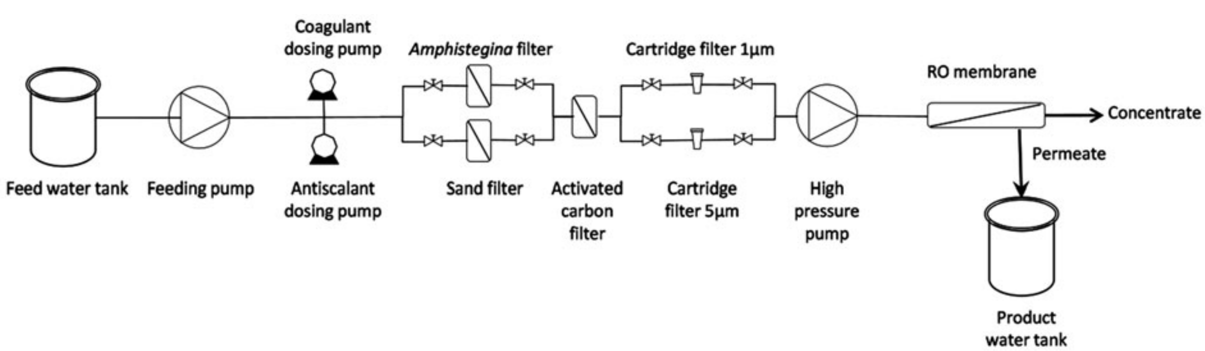

Fig. 2. Schematic diagram of a semi-pilot RO membrane pretreatment unit.

3. Results and discussion

3.1. Operating variables: coagulant, flow velocity, and temperature

Conventional pretreatment is not entirely secure to feed water quality that attends the recommendation of the RO membrane manufacturers. There are different types of coagulants such as ferric chloride ($FeCI_3$) and ferric chlorosulfate ($FeCISO_4$) and polyaluminum chloride (PAC). While Mitrouli et al. [26] illustrated that PAC has the smallest effect on the pH of seawater; our semi-pilot RO unit can be equipped with an online polyaluminum chloride (PAC)-dosing pump. Different PAC concentrations were used: 0.5, 1.0, 1.5, 1.8, 2.0, 3.0, 6.0, and 8.0 mg Al/l. According to the experimental observations, 1.5 mg Al/l of PAC appeared to be the most promising coagulant concentration to assist the performance of the mono media filtration vessels and to gives the optimum results of the filtration cycle time and filtrate quality parameters (lesser than that used by Mitrouli et al. by 0.3 mg Al/l). The concentration of the coagulant is kept constant in all the tests, whereas the variable parameters were the flow velocities (20, 40, and 60 l/min) and the temperatures (20, 30, and 40˚C) in the two filters. All the operating flow velocities and coagulant addition to the feed water caused a significant improvement in filtrate water quality resulting in low turbidity and $SDI_{15\ min}$ values for both filters. Therefore, there is no particle breakthrough occurred during the filter cycle for both filters and this fact can be attributed to the much larger and better adhering flocculates of coagulant medium, which can be formed and found to decrease as the temperature decreases [27].

The higher filtration rate (60 l/min) led to shorter filtration cycles which may cause plugging the filters. Furthermore, particle breakthrough is observed during filtration of feed water from sand and amphistegina filters after 6.0 and 9.0 h of continuous operation, respectively. At higher temperatures (30 and 40˚C) and application of coagulant dosage, no solids breakthrough was observed under any operating condition. In contrast to the lower working temperature (20˚C), the turbidity values were in the acceptable limits.

3.2. Silt density index

SDI was used as the main criterion of the filtrate quality during the semi-pilot sequences of the pretreatment processes. While, there are some disadvantages in using SDI as a measure of fouling potential of the water samples [28–30], it remains widely used as indicator in the desalination systems. Isaias [17] and Filmtec technical bulletin form of SW30HR LE-400 [25] found that SDI of less than 5.0 was appropriate for the SW membranes. On the other hand, Lorain et al. [31] and Chua et al. [32] confirmed that the inlet water quality with a 15-min SDI was lower than 3.0. Thereafter, the conventional pretreatment is not 100% secure to achieve these recommendations. In order to select the best SDI required for RO unit, the different pretreatment filtration systems for capturing particulates existing in seawater (sand, 5 and 1 μm cartridge prefilters) were compared with amphistegina filter. According to the results shown in Fig. 3, 1 μm cartridge filter has a higher impact on SDI than sand and 5 μm cartridge filters, but less than amphistegina filter. SDI test does not normally gives any information about the substantial quantity of particles that should probably exist in the sub-micron range and this means that the SDI of seawater is rather high even after passing through the 1 μm pre-filter. The colloidal particles and suspended solids are likely to plug the narrow feed channels of the RO membrane if they are not

Table 4
Specifications of Filmtec SW30HR LE-400 seawater reverse osmosis membrane

Parameter	Specification
Membrane type	Polyamide thin-film composite
Max. operating temperature, ˚C	45
Max. operating pressure, psi	1,200
Permeate flow rate, m^3/d	28
Active area, ft^2	400
Maximum element pressure drop, (bar)	1.0
Maximum feed silt density index (SDI)	5.0
Stabilized salt rejection, %	99.75
Pressure vessel diameter, inch	8.0
Pressure vessel length, inch	40
Free chlorine tolerance, ppm	<0.1

removed by the suitable pretreatment material. The SDI measurements at low and high temperatures as well as filtration velocities with no coagulant up to 15 min are higher than 5.0 as shown in Fig. 3. On the other hand, there is a great reduction in SDI values for each filter with coagulant addition at a concentration of 1.5 mg Al/l as shown in Fig. 4. Therefore, operating at the lower velocity 20 l/min and higher temperature 40˚C produced a filtrate of better quality for all media. But in case of amphistegina filter, the best and appropriate result (lower than 3) compared with the other pretreatment techniques results especially in case of sand filtration (3.8 SDI).

3.3. Turbidity

In Fig. 5, every type of media showed a definite reduction in turbidity. Therefore, the turbidity reduction at lower flow rate 20 l/min with no coagulant was found to be almost at the same trend for each filter. Mitrouli et al. found that there was a significant reduction of the turbidity measurements of the media filtration even without coagulant addition [26]. While in case of coagulant addition at a concentration of 1.5 mg Al/l at high temperature 40˚C, there was a greater reduction in turbidity value from 1.83 NTU of feed water down to 0.6 and less than 0.2 NTU. Therefore, it is observed that the much lower turbidity of less than 0.2 NTU was resulted in case of amphistegina filter, while the higher one was 0.6 NTU in case of sand filter. Consequently, the high filtration rate (60 l/min) led to higher turbidity and shorter filtration cycles which may cause plugging the filters, while at lower working temperature (20˚C), there was a lower reduction in turbidity values.

3.4. Total organic carbon

The likely presence of large macromolecules in the feed seawater were effectively aggregated by the coagulant and captured by the filtration media. Therefore, the TOC removal percentages were measured in all produced filtrates. The TOC reduction percentages that achieved by sand, 5.0 μm cartridge, 1.0 μm cartridge, and amphistegina filters were 57.7, 59.5, 61.5, and 67.3%, respectively and are shown in Fig. 6. These measurements were taken in the presence of 1.5 mg Al/l of PAC at higher temperature and lower flow

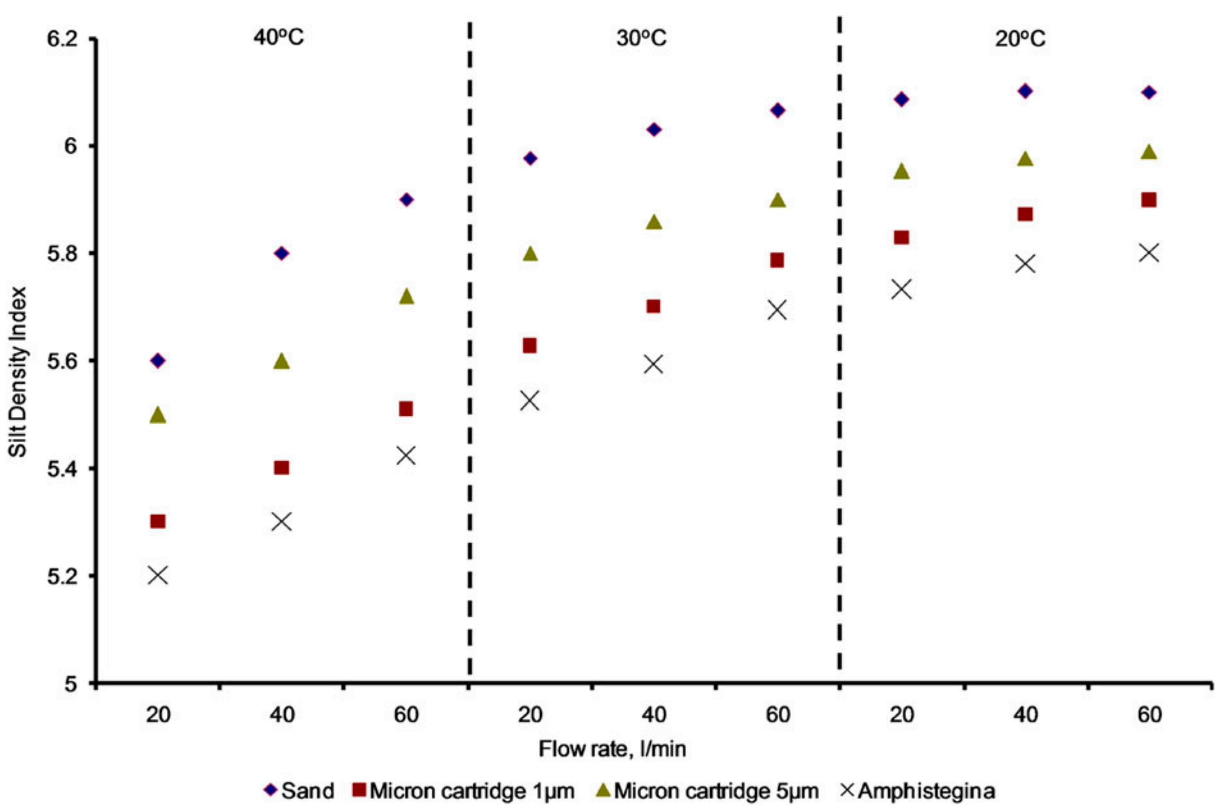

Fig. 3. SDI_{15} variation during operation without coagulant.

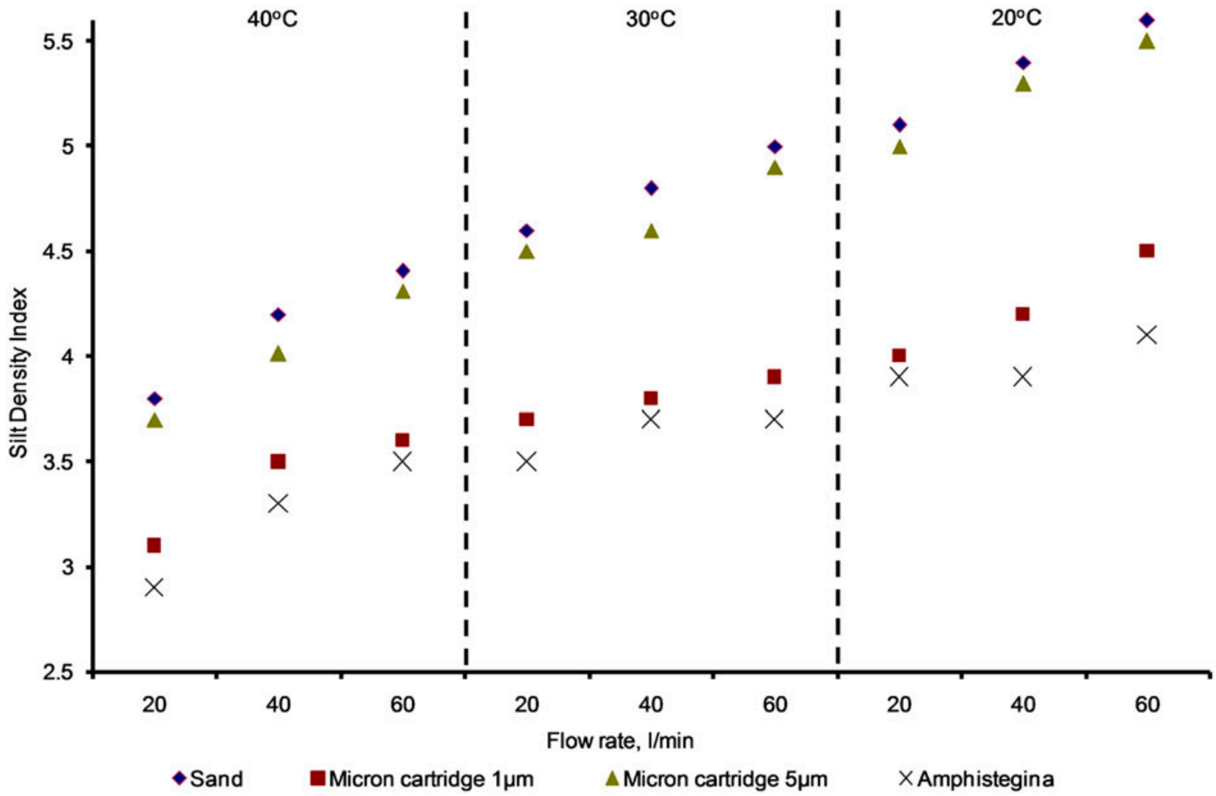

Fig. 4. SDI_{15} variation during operation with 1.5 mg Al/l of PAC coagulant.

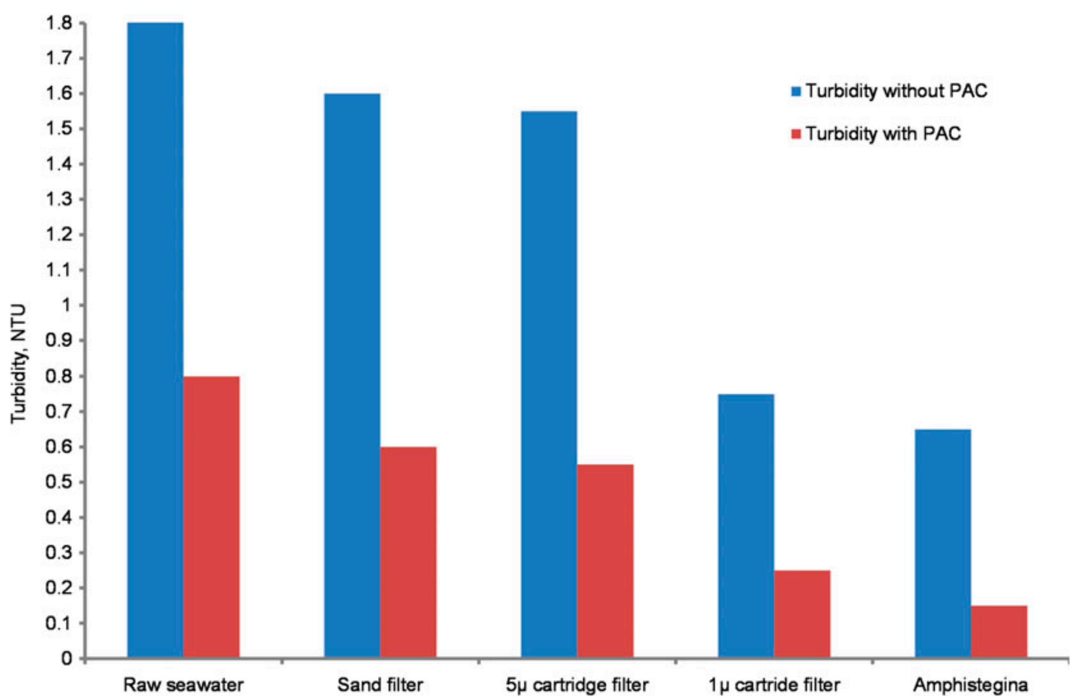

Fig. 5. Turbidity removal by different pre-filters at 20 l/min and 40˚C.

rate. At the same conditions and flow rate of 40 l/min, the TOC reduction was 59.6% in the amphistegina filter and 46.2% in the sand media. Finally, when the two filters were operated at flow rate 60 l/min, the TOC reduction was 49.6% for the amphistegina filter and 34.6% for the sand filter.

The greater ability of the amphistegina filter to reduce the TOC in the seawater can be explained by the differences in the mineral surface properties between quartz (sand) and calcite (amphistegina). There are some differences in the electron densities between quartz (SiO_2), which is the major constituent of sand, and calcite ($CaCO_3$), which is the major constituent of *Amphistegina* test [33]. Therefore, a common attribute of these electron dense minerals is the asymmetric distribution of electrons in the electron shell [34]. The separation of positive and negative charges leads to the formation of an electric dipole (polarization). Polarized structures attract other dipoles and establish bonds, e.g. van der Waals bonds. The partially charged ends are attracted to the partially charged ends of other polar molecules, e.g. organic particle contaminants. Potential dipoles that attach the mineral dipoles are hydrogen bonds or proteins with functional groups, e.g. OH groups and carboxyl groups [35]. Thereafter, this perhaps allowed the amphistegina to adsorb more organic particles and further investigations for this hypothesis and/or other reasons are needed to explain the ability of amphistegina filter to adsorb more organic particles.

3.5 AC filter

It is well known that the AC is dominantly used for purposes of adsorption of inorganic and organic compounds from aqueous solutions. While the adsorption of organic compounds from the liquid phase (mainly water) is more common than of inorganic compounds, and the adsorption of inorganic compounds from water is somewhat controversial and adsorption of organic molecules from water is equally complicated [36].

3.5.1. The effect of AC filter on TOC residual

Adsorption of organic solutes covers a wide spectrum of systems such as drinking water, wastewater treatments, and some of applications in the food, beverage, pharmaceutical, and chemical industries [37]. Therefore, AC adsorption has been cited by the US-EPA as one of the best available environmental control technologies. From the experimental studies, the best percentage reduction in TOC of 67.3% occurred in case of amphistegina filter and the lowest reduction of 57.7% occurred in case of sand filter at 40˚C, 20 l/min,

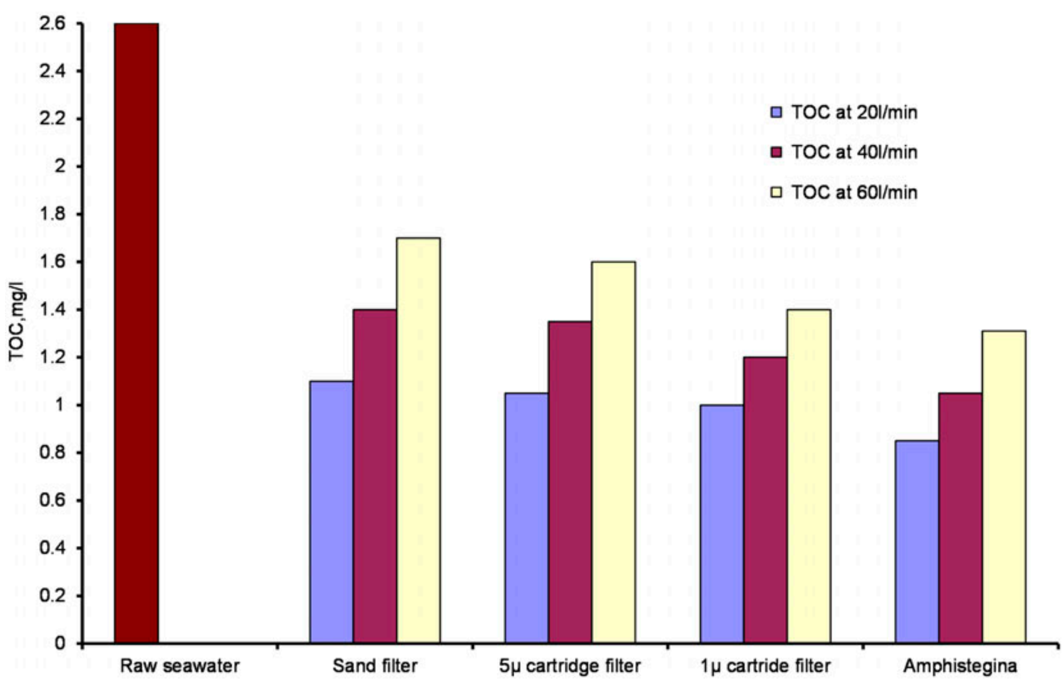

Fig. 6. TOC removal by different pre-filters at 40˚C and variable flow rates.

and 1.5 mg Al/l of PAC as shown in Fig. 6. But from Fig. 7, the total reductions of TOC after passing through AC filter for sand and amphistegina filtrates at the same flow rate and PAC concentration were exceeded to 90.4 and 97%, respectively.

3.5.2. The effect of AC filter on iron removal

Iron is found in surface and ground waters at varying concentration levels, usually up to 3–4 mg/l and in some cases up to 15 mg/l [38]. It was previously well known that fouling and scaling are the most serious problems in membrane processes and when the iron is present, even at low concentrations, it can be linked to aesthetic and operational problems [39]. Also, iron promotes the growth of a certain type of micro-organisms in water distribution systems, which leads to high operation costs for cleaning. According to the performance comparisons, which were presented by Bakr et al. [40] between conventional and specific pretreatment methods, we concluded that every method has advantages and disadvantages in application. Therefore, the most suitable pretreatment technique for iron removal was the AC filter which has higher adsorption capacity and led to a low operating cost. Depending on the concentration of iron in the feed water, direct filtration was used when the iron concentration is less than 5.0 mg/l [41]. From the experimental studies, Fig. 8 represents that all methods were effective in reduction of iron concentrations in the feed water for RO unit, but the most effective one was the AC filter after amphistegina filter in presence of 1.5 mg Al/l of PAC at 20 l/min and 40˚C.

Finally, we can also note from Fig. 8 that, in case of sand filter without coagulant and before passing through the AC filter, there was a slight removal of iron from 1.65 to 1.55 mg/l compared with the relatively high effect of the amphistegina media on iron removal from 1.65 to 1.20 mg/l.

3.6. Service, backwash and bed expansion

From the experimental studies, after the service period of filter (filter cycle), the filter became clogged by the retained particulates and it required cleaning. The filter cleaning took place by backwashing, using an upward high flow rate of seawater. Therefore, the experimental data based on the performance of the amphistegina and sand beds during service, backwash, and expansion are shown in Figs. 9–11, respectively. Since, the specific gravity of the calcite is 2.71 gm/cc while in quartz is 2.65 gm/cc, (for information see www.webmineral.com), the *Amphistegina* tests have a relatively higher weight than the quartz sand grains of the same size. Thereafter, the occurrence of

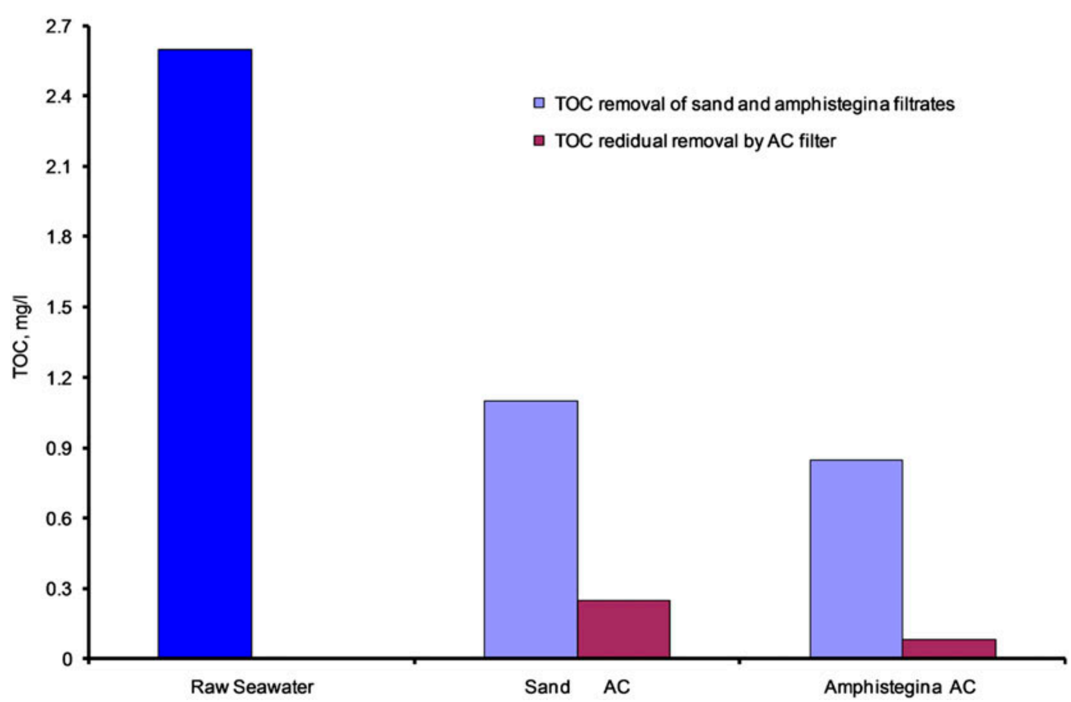

Fig. 7. TOC residuals removal by AC filter at 20 l/min, 40˚C.

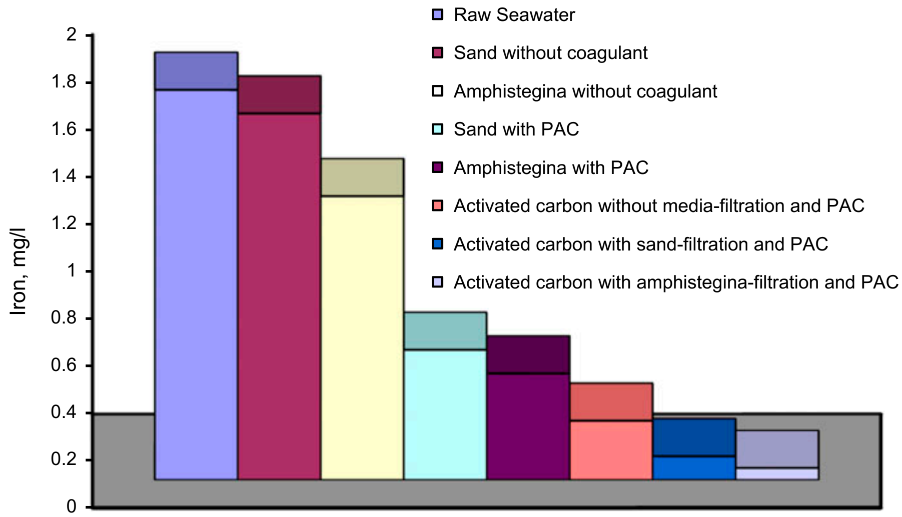

Fig. 8. Iron removal by AC at 20 l/min and 40˚C.

network of voids or chamberlets in the internal structure of *Amphistegina* tests reduced the overall weight and increased their buoyancy [22].

3.6.1. Service flow rate

As previously mentioned, the occurrence of network of voids or chemberlets in the internal structure of *Amphistegina* tests reduced the overall weight, which allowed using a higher bed capacity of 8.6 l compared with 6.6 l in case of sand filter. Therefore, the higher bed capacity for amphistegina filter led to the increase of efficiency of particulates capture and increased the production of pretreated seawater. From Fig. 9, at higher temperature 40˚C when the service flow rates of sand filter were 6.0 and 8.0 l/min, the service flow rates of amphistegina filter were 10 and 14 l/min. But at lower temperature 20˚C, when the service flow rates of sand filter were also 6.0 and 8.0 l/min, the service flow rates of amphistegina filter were decreased to 8.0 and 12 l/min and still higher than that of sand filter. From these data, we were noted that the produced water from amphistegina filter as filtrate is higher than that produced from sand

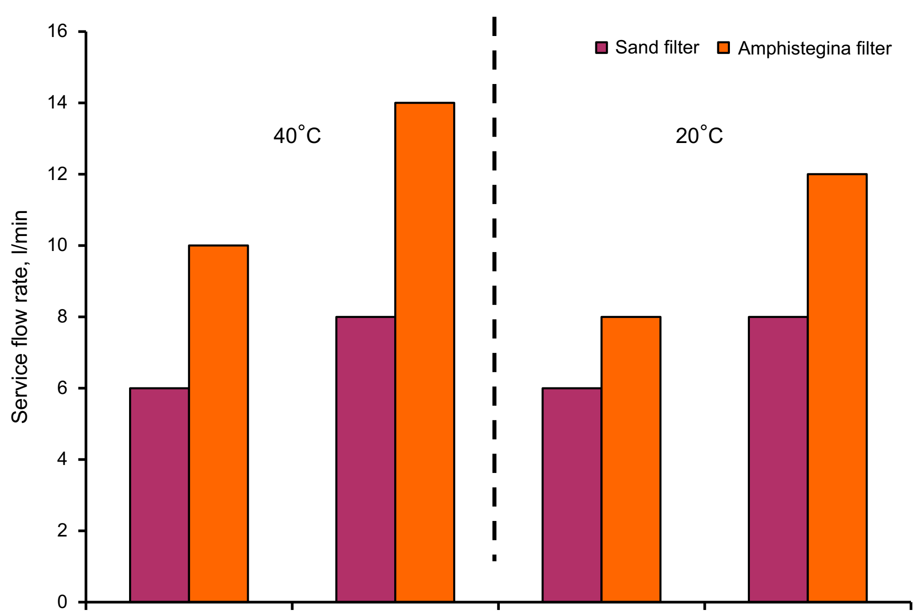

Fig. 9. Service flow rates of amphistegina and sand filters at different temperatures.

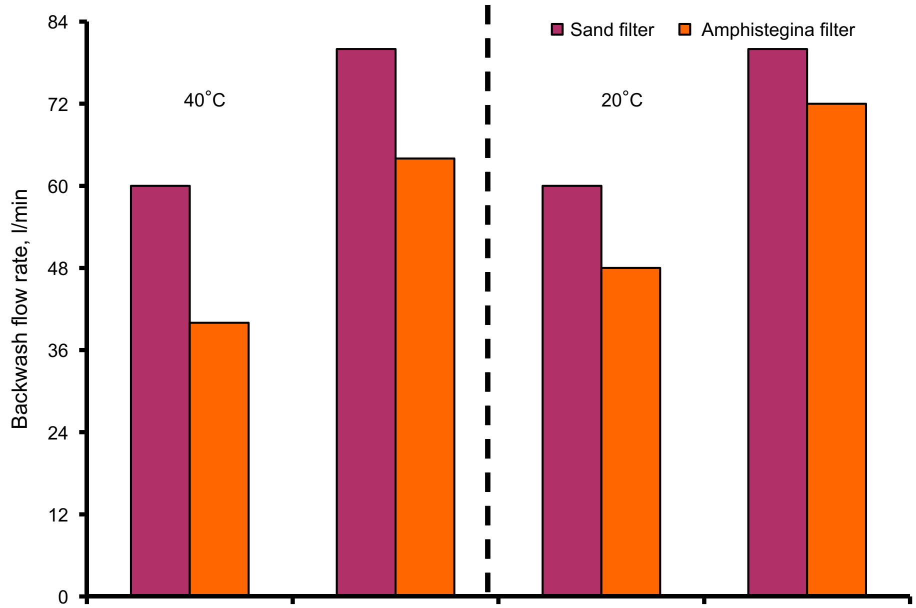

Fig. 10. Backwash flow rates of amphistegina and sand filters at different temperatures.

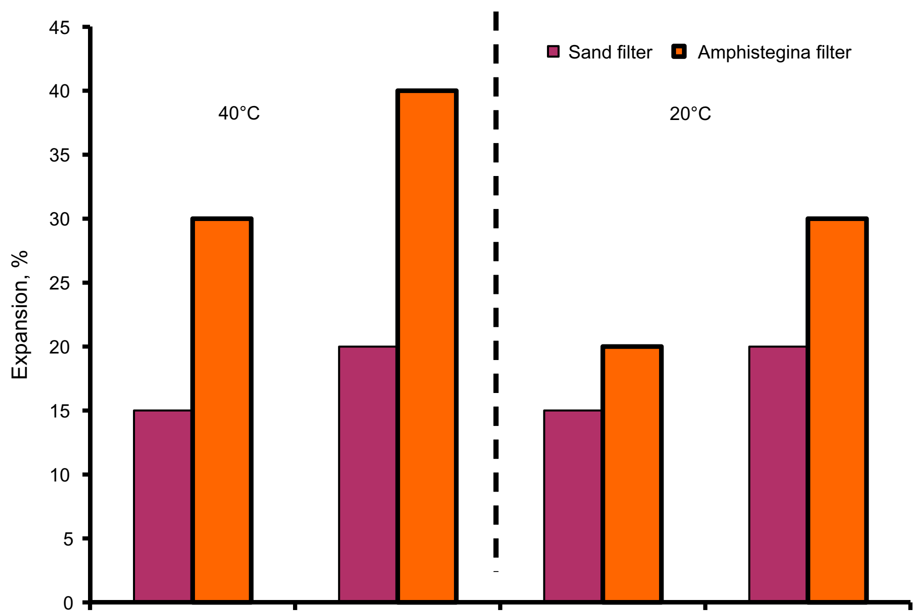

Fig. 11. Expansions of amphistegina and sand filters at different temperatures.

filter by 40% at higher temperature, while in case of lower temperature the produced water from amphistegina filter was still higher by 25% only.

3.6.2. Backwash flow rate

It is well known that the buoyancy of the *Amphistegina* tests was an advantage that led to the increase of their relative mobility during the backwash process, and hence, increased the quality of bed cleaning and so the lifetime of amphistegina filter. According to Figs. 9 and 10, at higher temperature when the service flow rates of sand filter were 6.0 and 8.0 l/min, the backwash flow rates required to clean the clogged sand bed were 10 times of these values. Therefore, in case of amphistegina filter, the service flow rates were 10 and 14 l/min and the backwash flow rates required to clean the clogged amphistegina bed were four times of the service values only. At lower temperature 20˚C, when the service flow rates of sand filter were also 6.0 and 8.0 l/min, the backwash flow rates required to clean the clogged sand bed were still 10 times of the service values. Thereafter, in case of amphistegina filter, the service flow rates were 8.0 and 12 l/min and the backwash flow rates were six times of service values only. From these data, the seawater consumption to clean the amphistegina filter in backwash process was lower than that of sand filter by 33.3% at higher temperature, while at lower temperature, it was still lower by 20% only.

3.6.3. Bed expansion

As mentioned formerly, the reduced overall weight and the buoyancy of *Amphistegina* tests maximized the bed expansion in amphistegina filter. Therefore, the bed expansion in amphistegina filter was gave a better cleaning quality, extended the bed lifetime, and decreased a seawater consumption of backwash process. Thereafter, it was evident that the amphistegina bed exhibited a greater expansion compared with the sand bed for the same operation temperature. From Fig. 11, similar trends regarding bed expansion as a function of temperature were found with sand as well as with amphistegina bed. At higher temperature of 40˚C, the bed expansions were ranged from 15 to 20% and from 30 to 40% for sand and amphistegina filters, respectively. While, at lower temperature 20˚C, the bed expansions were still ranged from 15 to 20% for sand filter and minimized to 20–30% for amphistegina filter.

4. Conclusions

The present study was depended on sediment samples of *Amphistegina* tests that were collected from Marsa Matrouh coast on the southern coast of the Mediterranean Sea. Therefore, the study investigated the applicability of *Amphistegina* tests instead of sand media filtration as new pretreatment media to seawater desalination plants. The results obtained from this study were:

- At lower flow rate 20 l/min and higher temperature 40˚C with addition of coagulant at a concentration of 1.5 mg Al/l, the amphistegina filter produced filtrates with a better SDI (lower than 3) and the sand filter was produced filtrates with a higher SDI (3.8 SDI).
- It was observed that much lower turbidity (less than 0.2 NTU) resulted in case of amphistegina filter and 0.6 NTU in case of sand filter.
- The amphistegina filter achieved a TOC reduction of 67.3%, while a TOC reduction for sand filter was 57.7% at flow rate 20 l/min. Therefore, when the two filters were operated at 60 l/min flow rate, the TOC reductions were 49.6% for amphistegina filter and 34.6% for sand filter.
- The total reductions of the residual TOC values after they passed through AC filter for sand and amphistegina filtrates were exceeded to 90.4 and 97%, respectively.
- At higher temperature, the service flow rate of amphistegina filter was higher than that of sand filter by 40%, while in case of lower temperature, the filtrate produced from amphistegina filter was still higher by 25% only.
- The consumption of seawater to clean the amphistegina filter in backwash process was lower than that of sand filter by approximately 33% at higher temperature. While at lower temperature, the difference was reduced to 20%.
- The bed expansions at higher temperature were ranged from 15 to 20% and from 30 to 40% for sand and amphistegina filters, respectively.

Acknowledgments

The authors express their appreciation to Prof. Dr Naglaa Ali, Egyptian Petroleum Research Institute and Dr Usama F. Kandil, associated professor in EPRI (M.Sc. and Ph.D. from Pennsylvania State University, USA) for their assistance and revision of this paper. The authors also would like to thank both of the anonymous reviewers and editor for their valuable comments on the manuscript.

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