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Improving water desalination efficiency by using carbon nanotubes as pre-treatment

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Abstract. Filters based on carbon nanotubes (CNTs) have been highlighted as an emerging technology for water desalination. In this paper, the weight percentage (wt.%) of CNTs required for desalination is discussed. The idea is based upon addition of CNTs to simple filters that is employed as adsorbent for dissolved solids in water (sodium chloride removal). Different CNTs filters (using CNTs Multi walled tube type) specimens were fabricated. Experimental work was done, through building a test rig, to show the effect of percentage of weight of CNTs on desalination of (Red Sea and Brackish) water. The effect of multiple filtration stages has been also shown. It was shown that the filters containing CNTs would be effective if used at the intake of modern RO (Reverse Osmosis) water desalination plants. Using filters with CNTs as pre-treatment of intake water for the RO units will reduce feeding pressure, specific energy and power consumption.

1. Introduction

Desalination means that removal of dissolved mineral salts from water (brackish water or seawater). About 71% of the earth surface is covered by water in form of the oceans, seas and the ices in the poles. However, only about 3% of water is fresh and suitable for use. Whereas, the water of the oceans and seas have high salt concentration. Therefore, some special processes are needed for desalination to overcome the water shortage [1–5]. Conventional methods for water desalination are being used to remove dissolved minerals and ions including oxidation, ion exchange reduction, membrane filtration and adsorption [6,7]. Yunhui Wang et al. [8] have used Nano-porous graphene for water desalination under external pressure, the graphene membrane has rejected the salt while transmitting water with good performance.

CNTs, a filter in carbon family, are relatively adsorbents that have been proven for removing many kinds of pollutants such as dioxin from air [9] and dissolved minerals from water [10,11]. CNTs powder is mixed through ultrasonic techniques with salty water for desalination. This technique has shown to be unaccepted due to its high cost and the difficulty of removing powder of CNTs from salty water.

Therefore, CNTs filters were synthesized as a practical adsorbent for economical desalination, without any leakage of CNTs into water. The objective of the present work is to study the effects of

CNTs on water desalination. Effects of percentage of weight (wt.%) of CNT in filters on initial salt concentration for RO units were also investigated.

1.1. Carbon Nanotubes
Several techniques have been developed to produce carbon nanotubes in sizeable quantities, including arc discharge, laser ablation, high-pressure carbon monoxide disproportionation (HiPco), and chemical vapor deposition (CVD). Most of these processes take place in vacuum or with process gases. CVD growth of CNTs can occur in vacuum or at atmospheric pressure. Large quantities of nanotubes can be synthesized by these methods; advances in catalysis and continuous growth processes are making CNTs more commercially viable.

1.1.1. CNTs Synthesis The type of CNTs is Multi walled tube. CNTs were synthesized by the electric arc discharge. The arc is generated between two electrodes (size φ 6 x 100 mm) using Distilled water. The cathode and the anode are from graphite (99.9% pure), and was performed under AC current, 75 A and 75 V. Figure 1 shows a view and a real photograph of the fully automatic machine for producing CNTs, this was designed and produced in Akhbar El-Youm Academy CNTs laboratory (through which the CNTs were brought and used in this work) . Each part is pointed out as follows: (1) Base frame, (2) lower tank, (3) fans for cooling, (4) valve, (5) upper tank, (6) carbon holder, (7) control unit, (8) electrical unit, (9) steeper motor, (10) nuts housing, (11) deionized water, (12) power screw, (13) bearing, (14) cover, (15) pure graphite, (16) cover hand [12].

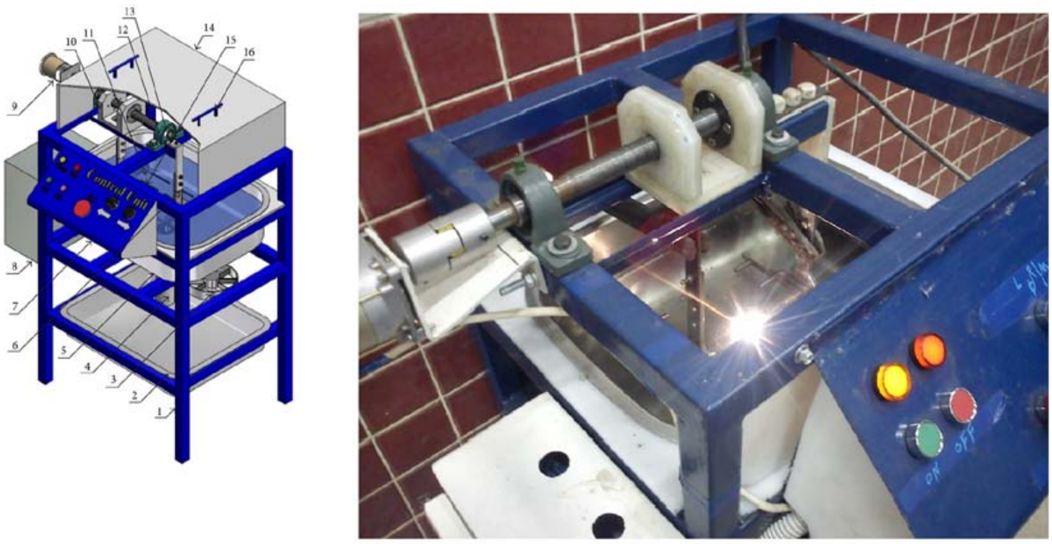

Figure 1. Automatic Machine for Producing CNTs *(through which the CNTs were brought and used in this work)* [12].

1.1.2. CNTs Specifications Produced CNTs using arc discharge were characterized with scanning electron microscope (SEM: BPI-T) and high-resolution transmission electron microscope (HRTEM: JEM-2100). Figure 2 shows the SEM image of the synthesized CNTs sample. Through transmission electron microscope (TEM) measurements, it can be observed CNTs are typically of 3-10 nm in diameter and on the order of 0.5–1 mm long, together with some amorphous carbon and graphite flakes, as shown in figure 3 and figure 4.

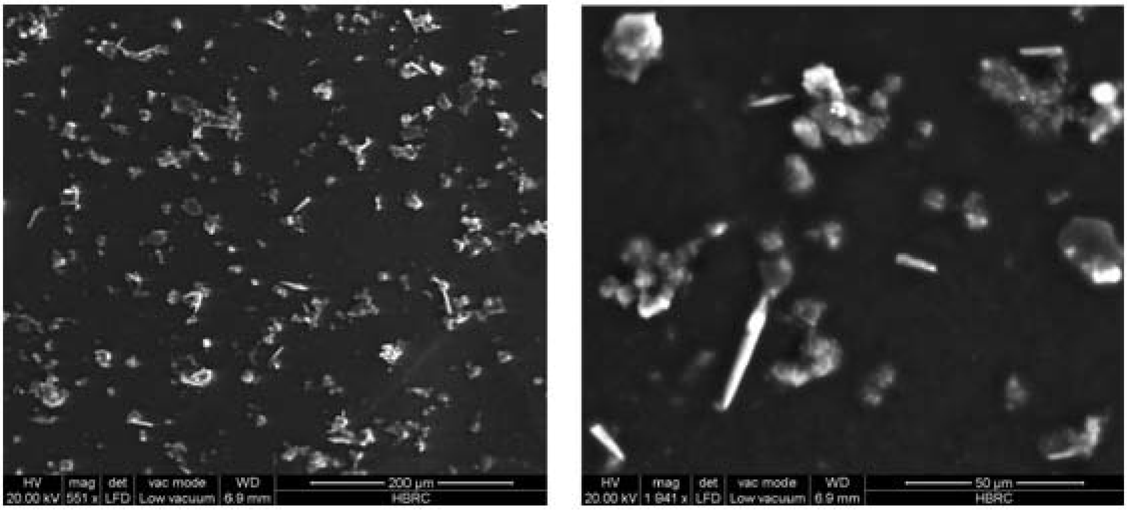

Figure 2. (SEM) images of the CNTs which were synthesized [12].

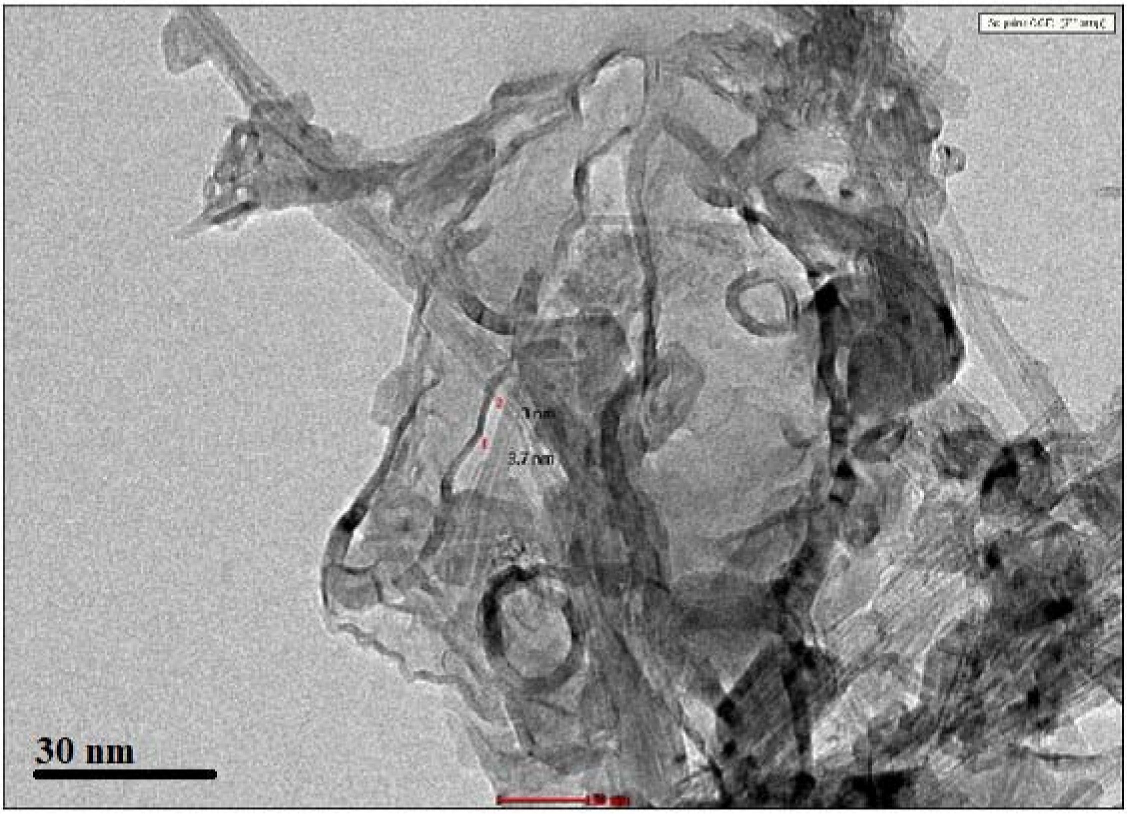

Figure 3. HRTEM image of the sample which were synthesized [12].

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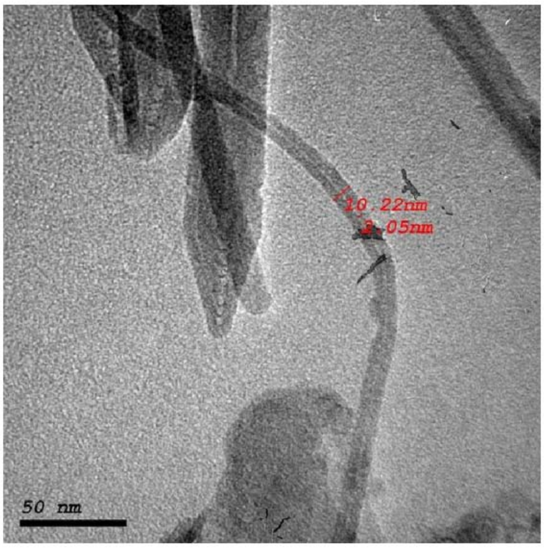

Figure 4. HRTEM image of a Multi Walled CNTs bundle [12].

2. Experimental Procedures
The main idea of CNTs filter desalination is based on the batch adsorption, where the dissolved salts are adsorbed inside the CNTs. The next part shows the experimental work which has been accomplished, presenting a detailed description of test rig specifications, synthesis of CNTs filters and experimental procedure.

2.1. Test Rig
A test rig was built to test the effect of CNTs filters with different wt.%, on different salty water types by using several stages. The test rig is a filtration unit which provides water desalination without phase change. This unit consists of inlet tank that is directly connected to the pump, the pump delivers the water to CNTs filter (specimen to be tested) finally after soaking of water inside the filter, water is transferred to the outlet tank, as shown in figure 5.
The rig specifications are as follows:

a) Tank capacity: 1 Liter,
b) Pump type: Diaphragm electric motor driven pump with 125 PSI maximum pressure, 1.2 Liter/min open flow rate and maximum power of 28 Watt.

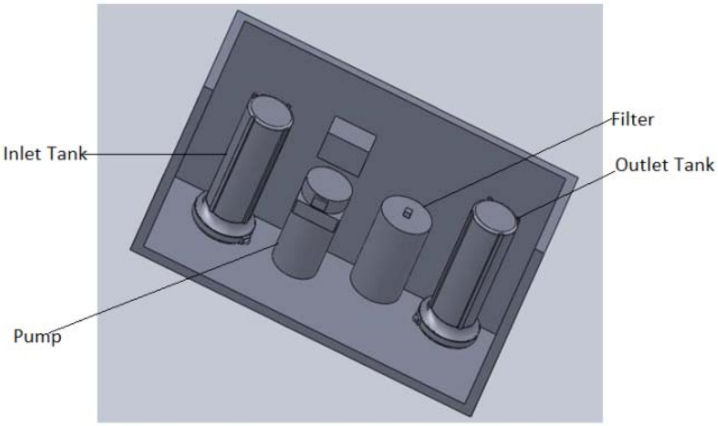

Figure 5. Test Rig used.

2.2. Synthesis of the CNTs filters

The CNTs filter consists of; Granular Activated Carbon (GAC), CNTs (Multi walled tube-type), epoxy (OXSIED 50 (KI) and EUXIT 50 (KII)), as shown in Table 1. GAC is the matrix material for the CNTs filter, it is a favored water treatment material as it removes organics and residual disinfectants contaminants from water. GAC is mostly made from raw materials such as nutshells, wood, coal and petroleum. The two principal mechanisms by which GAC removes contaminants from water are adsorption and catalytic reduction. The epoxy OXSIED 50 (KI) is a type of epoxy used for attraction between GAC particles. EUXIT 50 (KII) is a hardener for the epoxy. Epoxy resin is also a durable product which can be used with various materials, including wood, fabric, glass, or metal. It's important to note, however; epoxy resin is not considered to be water resistant [14].

Table 1. CNTs Filters Specifications.

Unit (gram)	Specimen					
	Filter No.1: 0%	Filter No.2: 0.5%	Filter No.3: 1 %	Filter No.4: 1.5%	Filter No.5: 2%	Filter No.6: 3%
KI (1/16 GAC)	10.000	10.050	10.100	10.150	10.200	10.300
KII (1/3 KI)	3.333	3.350	3.367	3.383	3.400	3.433
GAC	160.00	160.000	160.000	160.000	160.000	160.00
CNT (%GAC)	0.000	0.800	1.600	2.400	3.200	4.800

One of the challenges in the manufacturing process of CNTs is the well dispersion of CNTs into the matrix material. Only well separated and homogeneously distributed nanotubes can lead to unique properties of the material. To reach this goal; a well proven Ultrasonic dispersion technique was used. Typical procedures and same parameters used by Bittmann et al. for CNTs dispersion in epoxy resin was typically repeated [13]. An ultrasonic horn was used to disperse CNTs powder into epoxy resin. The fabrication of Nano phased epoxy was carried out in the following steps:

a) The CNTs are ultrasonically mixed with OXSIED 50 (KI) of epoxy resin.
b) CNTs were added by 0.5, 1, 1.5, 2 and 3 wt. %, respectively by weight of the resin.
c) The mixing process was carried out in an ultrasonic processor up to 200 sec, with the following parameters:
   i. Power: 200 watts.
   ii. Frequency: 24 kHz.
   iii. Amplitude: 20-100%.
   iv. Pulse: 0-100%.
d) The mixing is carried out at 55% of the amplitude and for about 20 min for 0.5, 1, 1.5 wt.% and 90 min for 2 and 3 wt. % of the resin.
e) In order to avoid rise in temperature during sonication, the mixing beaker is placed in a cooling mixture of ice and water.
f) The CNTs powder is gradually added into the mixing beaker, mixing process took 20 to 90 minutes depending on the composition. Figure 6 shows the mixing process.
g) Hardener EUXIT 50 (KII) is added to the mixture at a ratio of 1:3. The mixture is then poured into the mold, figure 7 shows the molding process.
h) The tube is left to cure at room temperature for 5 days to completely solidified.

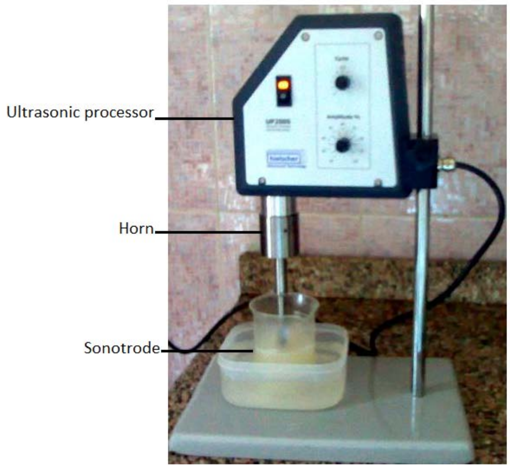

Figure 6. Ultrasonic mixing process.

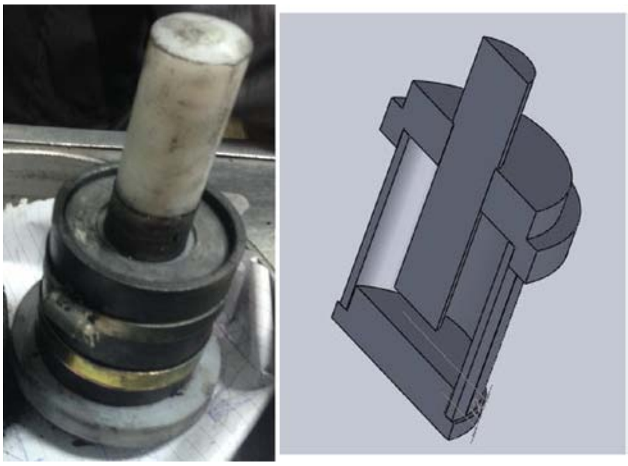

Figure 7. Moulding process

Six different filters with the following dimensions were produced:

a) Outer diameter 65 mm.
b) Inner diameter 30 mm.
c) Height 75 mm.

The filters finally appeared, as shown in figure 8. Table 1 shows the specifications of produced filters and their compositions percentages.

Figure 8. Final CNTs filters.

IOP Conf. Series: Materials Science and Engineering **973** (2020) 012016 doi:10.1088/1757-899X/973/1/012016

2.3. Measurement procedures
The efficiency of desalination of the proposed filters were examined using salty water samples from Red Sea and brackish. Brackish water sample was brought from a deep well (water depth; 21 m) at Wadi El Natroun area 100 Km North Cairo. Several experiments have been performed via soaking of Red Sea and brackish water through the test rig. All the water samples have been sent for examination (dissolved salts concentration) at Governmental certified labs of the Ministry of Agriculture in Egypt. The effect of CNTs filters desalination was examined for each of the 6 filters (0, 0.5, 1, 1.5, 2 and 3 wt.% of CNTs) for Sea and brackish water at room temperature. The filter with highest performance has been examined to see the effect of multiple desalination stages on its performance.

3. Results and Discussion
The effect of weight percentages of CNTs and number of filtration stages on desalination were investigated. Figure 9 and figure 10 show the effect of water desalination when using different percentages of CNTs filters. It was shown that filter without CNTs (0 wt.%) almost has no effect on desalination (dissolved salts were reduced by 9.2 %, from 39,963 of the raw water to 36,983). Increasing the weight percentages of CNTs has increased the water desalination effect. The laboratory analysis results show that the Red Sea water dissolved salts were reduced by 27.3% (from 39,963 PPM of the raw water to 29,057 PPM) when using CNTs of 3% wt. The filter with best performance was selected to show the effect of using series of this filter (multiple filtration stages). Figure 11 and figure 12 show the effect of number of filtration stages when using 3% wt. CNTs filter on dissolved salts of Red Sea water sample. It was shown that the Red Sea water dissolved salts concentration has been reduced by a ratio of 53.8% (from 39,872 PPM of the raw water to 21,440 PPM) when using 5 stages of CNTs filter (3% wt.).

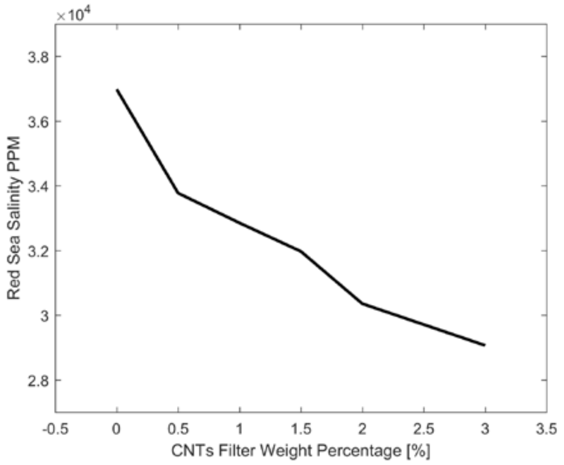

Figure 9. Effect of CNT wt.% on Dissolved Salts of Red Sea Water.

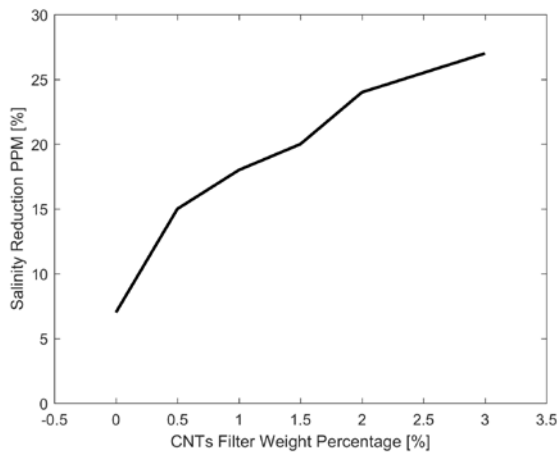

Figure 10. Effect of CNTs Weight on Reduction Percentage of Dissolved Salts for Red Sea Water PPM%.

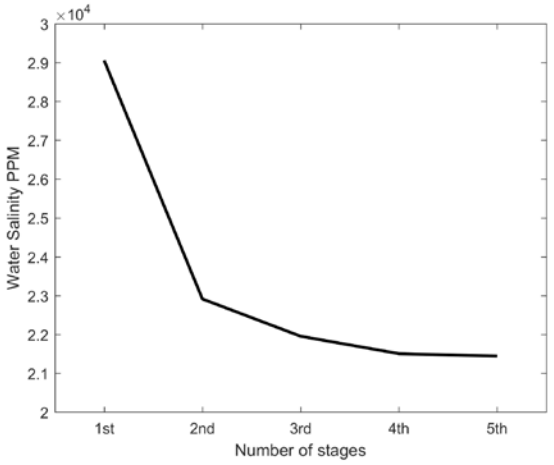

Figure 11. Effect of Filtration stages at 3 wt.% filter on Dissolved Salts of Red Sea Water.

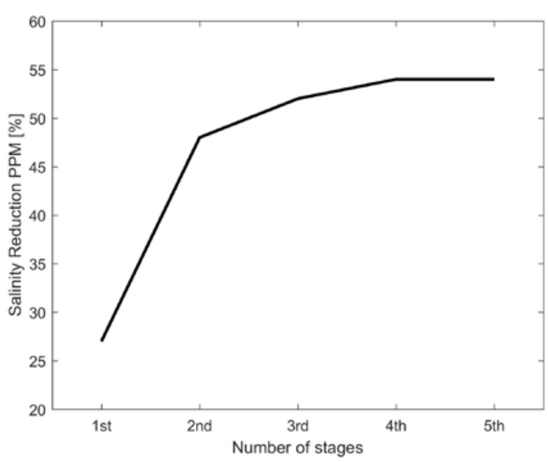

Figure 12. Effect of Filtration Stages on Reduction Percentage of Dissolved Salts for Red Sea Water PPM%.

Same experimental procedures were repeated for brackish water. Figure 13 and figure 14 show the effect of percentages of CNTs on brackish water dissolved salts. The laboratory analysis results show that the brackish water dissolved salts were reduced by 44.6 % (from 7,168 PPM of the raw water to 3,968 PPM) when using CNTs filter of 3% wt. CNTs filter of 3% wt. is shown to have the best performance. Figure 15 and figure 16 show the effect of number of filtration stages on salinity. It was shown that the brackish water dissolved salts concentration has been reduced by about 60% (from 3,968 PPM to 2,835 PPM) when using 3 stages of CNTs filter (3% wt.). Using more than 3 stages shows that there is almost no effect on desalination.

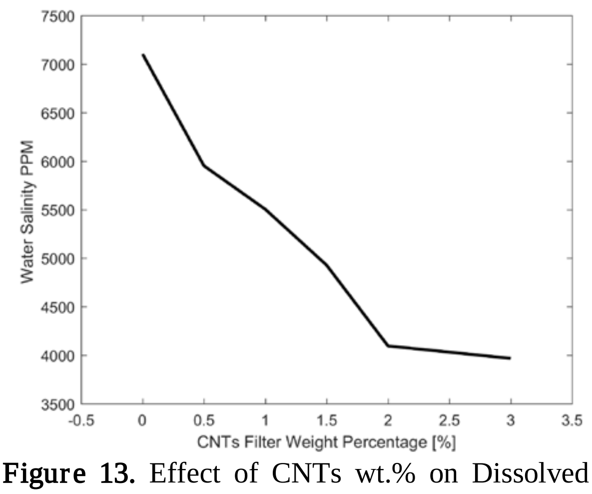

Figure 13. Effect of CNTs wt.% on Dissolved Salts of Brackish Water.

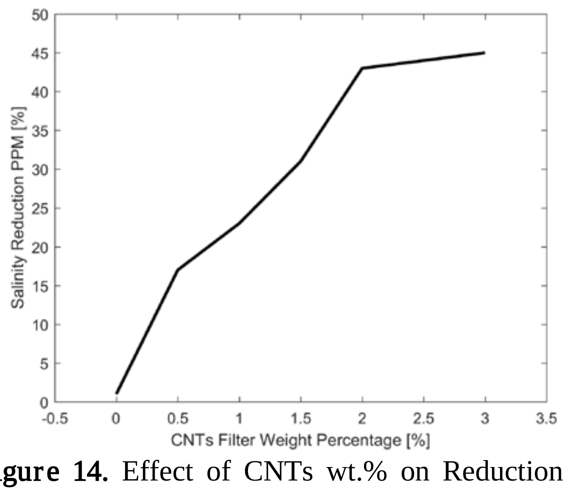

Figure 14. Effect of CNTs wt.% on Reduction Percentage of Dissolved Salts for Brackish Water.

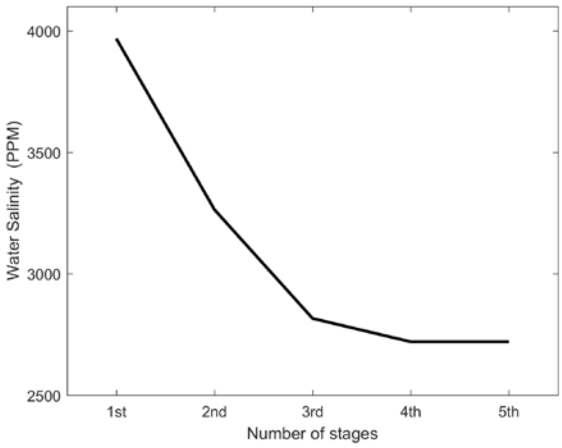

Figure 15. Effect of Filtration Stages at 3% wt. filter on Dissolved Salts for Brackish Water.

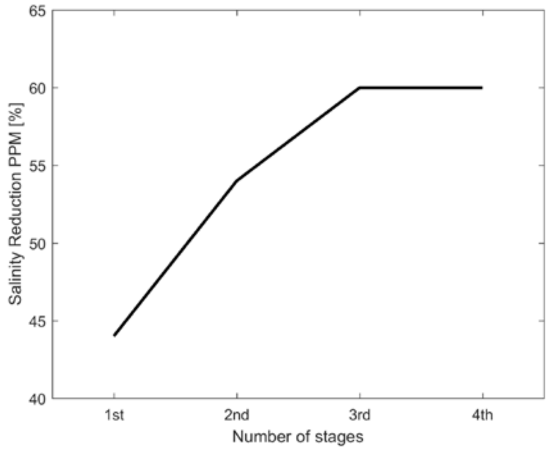

Figure 16. Effect of Filtration Stages on Reduction Percentage of Dissolved Salts for Brackish Water PPM%.

3.1. Combining carbon Nanotubes filters with RO desalination units

Reverse Osmosis technique is widely used now for water desalination processes. Cost of water desalination using RO filters is mainly depending on power consumed for raising water inlet pressure, this is directly related to inlet water salinity. The target is to show the effect of reduction in pressure and power consumption when using CNTs coupled to the RO desalination plant to simulate its effect on energy reduction. The effect of using CNTs filter attached with RO plant; for Red Sea and brackish water desalination was studied through well proven software modeling. Reverse Osmosis System Analysis (ROSA) software is used for modeling, it is one of the leading RO system design tools used to design RO plants. The same parameters for the samples with and without CNTs filter effect was stated; the raw water flow rate, inlet pressure, chemical dosage, total membrane active area. The filter with best performance was simulated when coupled with RO plant through several filtration stages for Red Sea and brackish water.

Simulation results show a considerable reduction in the plant's power, pressure and energy consumption. Figure 17 shows a reduction of 24.3% in power, pressure and energy consumption when using 3% wt. CNTs filter. Figure 18 shows the effect of using 3% wt. CNTs filter on several stages. For Red Sea sample analysis, it was shown that a reduction percentage of 44.5% in power, pressure and energy consumption was achieved after 3 stages (the values of the reduction in power is the same as the reduction in Pressure), while almost no reduction was shown during 4th and 5th stages. Brackish water was simulated; figure 19 shows the reduction percentage achieved for different weight percentages of CNTs filters. A Maximum reduction in energy of 24% was shown when using a filter of 3% wt. Figure 20 shows a maximum reduction of 46.1% for energy when using the 3% wt. filter for 3 filtration stages.

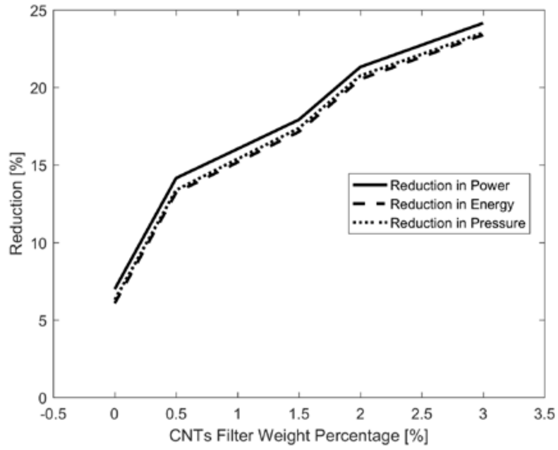

Figure 17. Effect of CNTs wt.% on Percentage of Reduction in Power, Energy and Pressure for Red Sea Water.

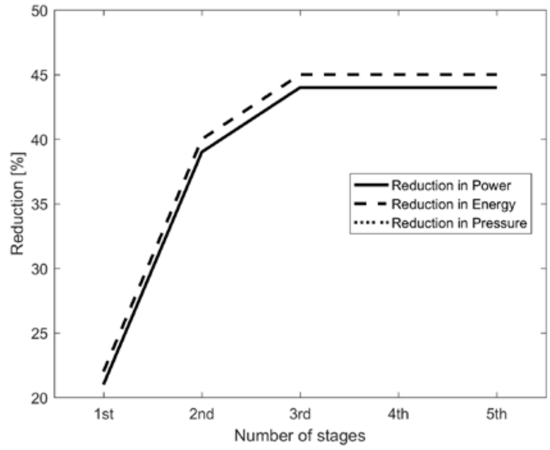

Figure 18. Effect of Filtration Stages at 3 wt.% filter on Percentage of Reduction in Power, Energy and Pressure for Red Sea Water.

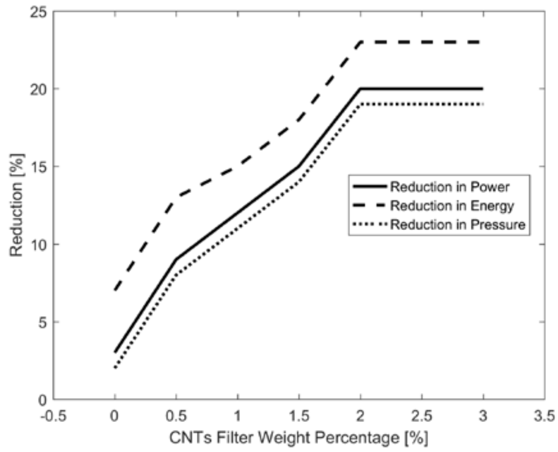

Figure 19. Effect of CNTs wt.% on Percentage of Reduction in Power, Energy and Pressure for Brackish Water.

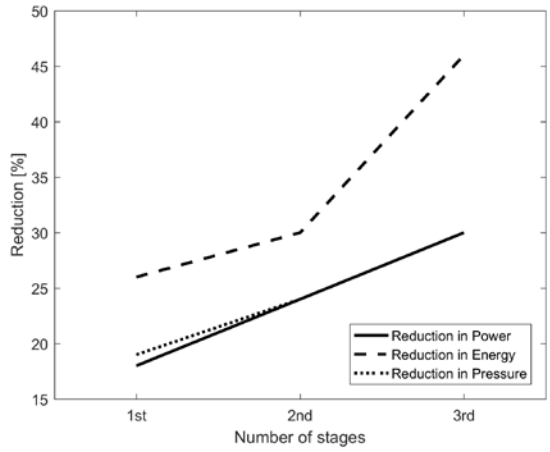

Figure 20. Effect of Filtration Stages at 3 wt.% filter on Percentage of Reduction in Power, Energy and Pressure for Brackish Water.

4. Conclusion

CNTs filters as an emerging technology is shown to be a promising solution for water desalination. A test rig was built, different CNTs filter specimens were fabricated for testing the effect of CNTs on desalination. It was found that addition of CNTs (Multi-tube type) to epoxy resin with granular activated carbon (GAC) can increase the rate of desalination of water. Experimental work was done to show the effect of weight percentage of CNTs on water desalination. Water samples used was from Red Sea and brackish (a deep well of water depth; 21 m). Several experiments were performed via soaking of Red Sea and brackish water through the test rig. Water samples were sent for examination of dissolved salts concentration at Governmental certified labs of the Ministry of Agriculture in Egypt. Several experiments were done without and with CNTs; where CNTs content reached 0.5, 1, 1.5, 2 and 3 wt. %. The effect of multiple filtration stages were also shown. Filters without CNTs (0 wt. %) were shown to have no effect on salinity. This can be used for a variety of agricultural crops withstanding medium salinity such as soya beans, mango, grapes, etc.

IOP Conf. Series: Materials Science and Engineering **973** (2020) 012016 doi:10.1088/1757-899X/973/1/012016

The effect of using CNTs filter (as pre filtration) attached with RO plant; for Red Sea and brackish water desalination was simulated. Well proven software modeling; Reverse Osmosis System Analysis (ROSA) software was used for modeling. CNTs filters output were simulated, results showed a considerable reduction in the plant's power, pressure and energy consumption. Software simulation for RO water desalination units show that using filters with 3 wt.% after 3 stages can reduce significantly feeding pressure and specific energy. Hence, it was shown that the consumed power will be reduced by 45% for Red Sea desalination, whereas, for brackish water the consumed power could be reduced by 24%. This would impact highly the production cost for desalinated water as it is well known that more than 50% of the production cost is due to energy consumption.
As a future work more analysis must be done to study the interaction between water and filter and expected degradation rate of filter and the effect of filter on pollutant water and its effect on the water quality and health in case of water direct using.

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