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Effect of Chemical Pretreatment on the Seawater Fouling Potential

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Abstract- In this research, three pretreatment chemicals, ferric chloride, aluminum chloride, and powdered activated carbon, were applied at different concentrations to a raw seawater feed. Five different concentrations (2, 5, 10, 15, and 20 ppm) of each chemical were used to examine the effect on reducing the silt density index (SDI) of raw seawater. The best overall reduction in SDI, 10.05, was obtained with ferric chloride at a concentration of 10 ppm. At higher concentrations of ferric chloride, the SDI did not improve and instead increased. The same behaviorwas observedwith powdered activated carbon (PAC), where a higher concentration resulted in a higher SDI. The SDIsof seawater treated with 2 and 20 ppm aluminum chloride were almost the same – 12.7 and 12.1, respectively. The study shows that using higher concentrations of chemical coagulant may produceadverse results rather that improving the SDI of seawater. Chemical pretreatment should be optimized according to the type and quality of the feed water.

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Strictly as per the compliance and regulations of:

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I. Introduction

Although 70% of our plant is covered with water, only 3% is fresh water, and only one-third of the 3% is available for use (approximately 60% is locked in glaciers as ice). As a result of the water shortage, approximately 2.7 billion people world wide experience water scarcity at least one month of the year [1]. As a direct result of the water shortage, proper sanitation is unavailable to billions of people. Waterborne diseases, such as cholera and typhoid fever, affect approximately two million people every year, most of them children [2].

The world water consumption rate increased six-fold from 1900 to 1995, more than double the rate of population increase over the same period [3]. Increasing population growth, climate change, and the construction of large agricultural projects exacerbate the water shortage problem. It is estimated that by 2025, two-thirds of the world's population will suffer water shortages.

About one-third of the world's population lives 100 kilometers from the seashore. Therefore, seawater desalination is considered an important solution for the world water shortage. Seawater reverse osmoses (RO) membranes can be used to treat seawater containing total dissolved solids in the range of 10,000 – 60,000 mg/L [4].

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Presently, seawater desalination has become an important source of fresh water production [5]. The salt concentration in seawater ranges from 15,000 – 50,000 mg/L total dissolved solids. The desalination of seawater can be achieved though several methods, such as multi-effect desalination (MED), multi-stage flash (MSF) distillation and RO. RO desalination has become the technology of choice recently because it is much less energy intensive than MSF technology. Fifty-one percent of the newly installed desalination capacity in 2001 and seventy-five percent of the new production capacity in 2003 are RO desalination systems [6]. The new, improved RO technology is considered to be the best choice for future desalination projects [7].

One major drawback of RO desalination technology is the susceptibility of the membrane to fouling, especially when the feed has a silt density index (SDI) larger than 3. RO membrane fouling can occur due to scaling by silica, $CaCO_3$, $CaSO_4$, $BaSO_4$, organic molecules, and suspended solids [8]. To ensure the successful implementation of RO desalination, a good pretreatment system must be used. A poor pretreatment system would result in lower permeate output, lower permeate quality, increased cleaning frequency, higher operating cost and, finally, membrane failure [9].The pretreatment process is critically important to ensure the successful operation of a RO desalination system [10].

Pretreatment can be done physically, using screening, sand filters, and/or cartage filters, or chemically, using anti-scale agents, coagulants, and disinfectants.

Ferric chloride, alum, and cationic polymers are regularly used as chemical coagulants in water desalination pretreatment systems to remove particles from raw water feeds [11].Ferric salts, especially ferric chloride, are among the most widely used chemicals for the pretreatment of seawater [12].

Furthermore, activated carbon is very effective and is the favored pretreatment for the removal of dissolved organic matter [13-14]. Gur-eznik et al. reported 80 – 90% removal of dissolved organic matter from membrane bioreactor effluents treated with activated carbon [15].

The SDI can be utilized to measure the success of the pretreatment method in reducing the fouling potential of the water fed to the desalination system.

The SDI is a parameter characterizing the fouling potential of water. Particulates, colloidal matter and microorganisms have a natural tendency to deposit on membranes, thus impairing their effectiveness. SDI is one of the most important parameters for the design and operation of reverse osmosis membrane processes.

The SDI is determined by measuring the plugging rate of a 0.45 μm microfiltration (MF) membrane using a constant 207 KPa feed pressure for a specified period of time. The SDI can be defined as the elapsed filtration time t_f. The ASTM describes this test as a standard test for determining the fouling potential of a feed water due to the presence of particles [16]. From a practical point of view, the SDI of a fine hollow-fiber RO feed water must be below 3.

$$SDI = \frac{1-({}^{t_i}/_{t_f})}{t_t} X\, 100 \qquad / \text{ min}) \qquad (1)$$

where:

t_i is the initial filtration time to filter a fixed volume (500 mL) in seconds

t_f is the final filtration time to filter a fixed volume (500 mL) in seconds

$t_t$is the total elapsed time of the experiment in minutes (5, 10, or 15 mins)

II. Materials And Methods

The procedure for measuring the SDI has been standardized by the ASTM [14]. The equipment and procedure used are as follows:

The apparatus was assembled as shown in Fig. 1, in which the feed pump was automatically controlled to provide a constant feed pressure of 207 ± 7 kPa (30 ± 1 psi).

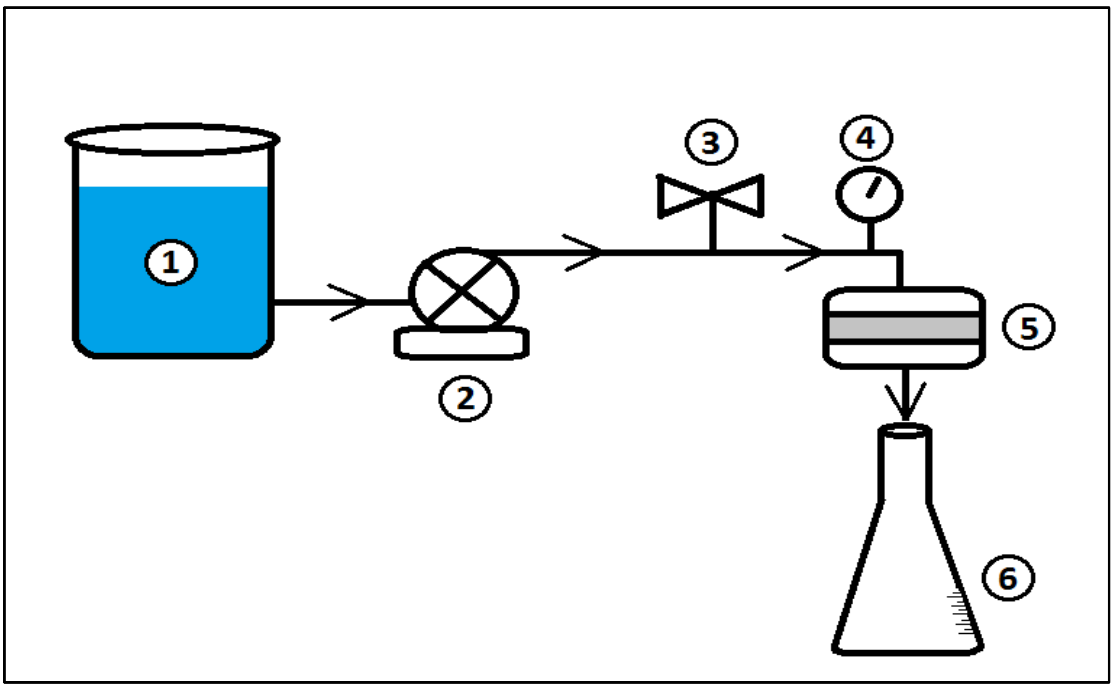

Fig. 1: SDI filtration apparatus setup. 1. treated sweater feed tank, 2. pump, 3. valve, 4. pressure gauge, 5.0.45 μm filter holder, 6. graduated cylinder.

Before installing the membrane filter, the water to be tested was flushed through the apparatus to remove entrained contaminants. The silt density index (SDI-5) was measured for sea water from Shuwaikh beach in Kuwait City. The total dissolved solids, electrical conductivity, and pH were measured for all sea water samples.

An Applied Membrane, Inc., Automatic SDI System (Y-SIMPLESDI-220) was used to measure the SDI of the seawater sample. Millipore cellulose acetate 0.45 μm micro filters were used for all filtration experiments. The pH of each sample was measured using a HANA INSTRUMENTS HI 8010 Basic Portable pH Meter. The electrical conductivity and total dissolved solids were measured using a HANN INSTRUMENTS HI 9835 EC/TDS/NaCl Meter.

It was impossible to complete the traditional 15-minute SDI tests (or even the 10-minute SDI test). The seawater samples were treated with power activated carbon (PAC), aluminum chloride ($AlCl_3$), and ferric chloride ($FeCl_3$). All of the chemicals used in this study were of ACS grade. The appropriate amount of each chemical was measured using a sensitive balance. In each pretreatment experiment, a 30 L solution was prepared with a concentration of 5,10 or15 ppm. The seawater was mixed with the pretreatment chemicals for 30 minutes at 500 RPM using a Servodyne mixer (Cole-Parmer Instrument, Vernon Hills, IL) with a high-lift blade. The treated water was allowed to settle overnight, and the clear supernatant water from the top was used for the SDI experiments. For each concentration of the pretreatment chemical, the experiment was repeated three times, and the average SDI-5 was calculated. The temperature was maintained at approximately 20 °C during all experiments.

III. Results and Discussion

The primary aim of the work presented here is to evaluate the fouling tendency of different types and concentrations of chemicals. The sensitivity of the SDI to wards the variation in the particle concentration and the testing parameters is described in (Table 1).

Table 1: Pretreated seawater analysis for different pretreatment chemicals and SDI-5 results.

	Ferric chloride (ppm)					Powder activated carbon (ppm)					Aluminum chloride (ppm)				
Concentration (ppm)	2	5	10	15	20	2	5	10	15	20	2	5	10	15	20
TDS (g/L)	33.1	29.6	29.7	30.1	31.3	32.3	28.16	30.23	29.36	32.1	32.7	32.3	32.3	30.9	30.2
pH	8.02	7.27	7.26	7.28	7.66	7.98	7.2	7.47	7.63	8.15	7.78	8.02	7.88	7.65	7.38
Conductivity (mS/cm)	66.2	59.1	59.3	60.3	62.6	65.0	58.1	60.6	58.7	64.2	65.4	64.6	64.7	61.8	60.4
Turbidity (NTU)	0.40	0.50	0.33	1.23	0.90	0.63	0.93	0.30	0.50	3.23	0.30	0.70	0.76	0.86	1.30
SDI-5	15.80	13.36	10.05	17.99	15.30	14.60	15.67	11.29	11.88	15.00	12.70	14.18	17.46	14.48	12.10

a) *Untreated Seawater Analysis*

It was impossible to complete the traditional 15-minute SDI test or even the 10- or 5-minuteSDI tests without treatment.

b) *Pretreatment Experiments*

i. *Ferric Chloride Pretreatment Experiments*

The average SDI-5 of seawater pretreated with 2, 5, 10, 15 and 20 ppm ferric chloride($FeCl_3$) was15.8, 13.4, 10.1, 18.0, and 15.3, respectively (Fig. 2). The best result was obtained with a $FeCl_3$ concentration of 10 ppm. The results show that 10 ppm $FeCl_3$ is better than 2 or5 ppm, and the SDI-5 was lowered from15.8 and 13.4 to 10.1 for 2 and 5 ppm $FeCl_3$, respectively; nevertheless, increasing the $FeCl_3$ concentration over 10 ppm had an adverse effect, increasing the SDI-5 value. Treatment with a higher dose of $FeCl_3$(15 and 20 ppm)did not improve the SDI-5. The SDI-5 increased to 18.0 and 15.3 for $FeCl_3$ concentrations of 15 and 20 ppm, respectively.

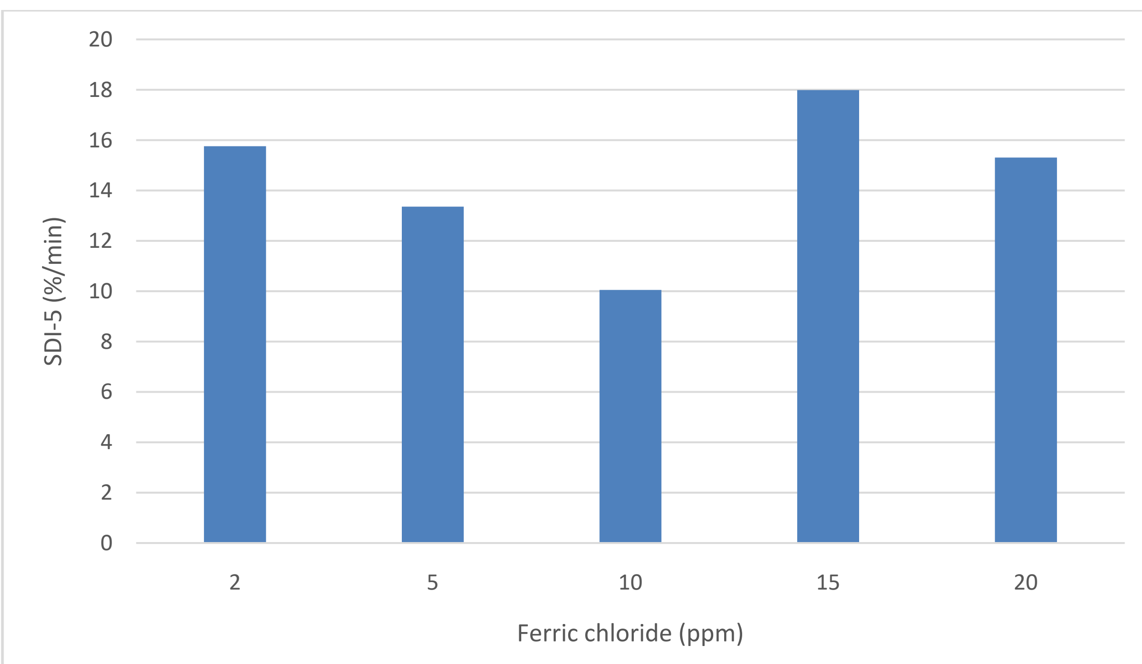

Fig. 2: Effect of pretreatment with ferric chloride on the SDI-5 of seawater.

ii. *Powder Activated Carbon Pretreatment Experiments*

The average SDI-5 of seawater pretreated with 2, 5, 10, 15, and 20 ppm PAC was14.6, 15.7, 11.3, 11.9, and 14.9, respectively (Fig. 3). The best result was obtained with a PAC concentration of 10 ppm (Fig. 3).

The SDI-5 results at different PAC concentrations are displayed in Fig. 3. The results show that 10 ppm PAC is better than 2 or5 ppm. Treatment with a higher dose of PAC resulted in a higher SDI-5. Treatment with 15 and 20 ppm PAC did not improve the SDI-5.

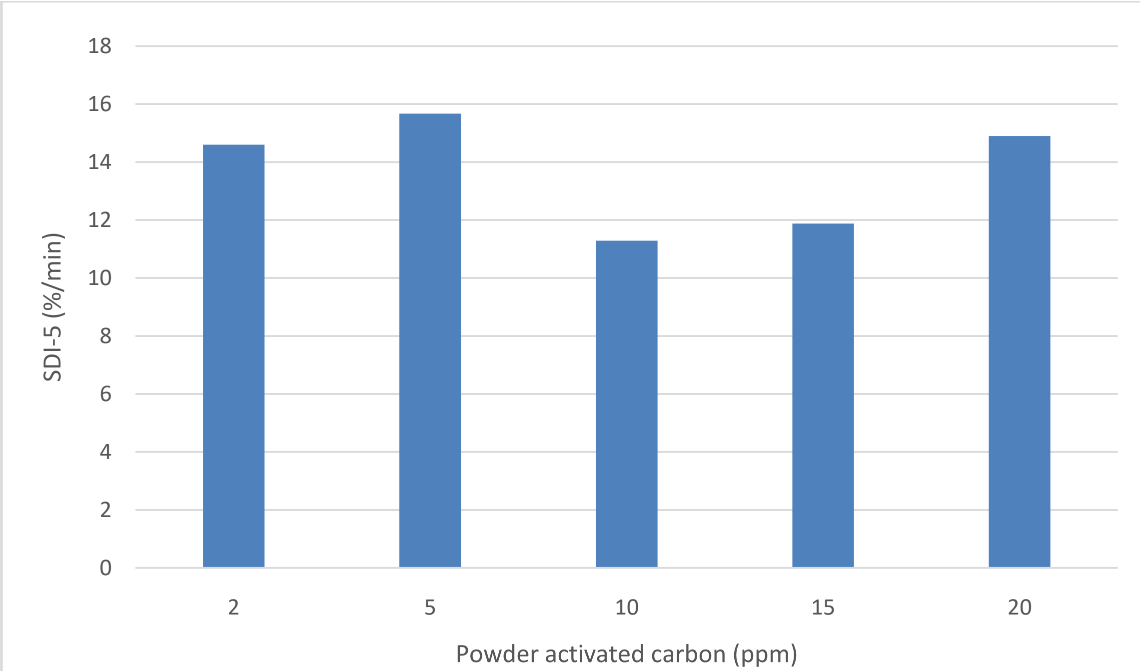

Fig. 3: Effect of pretreatment with PAC on the SDI-5 of seawater.

iii. *Aluminum Chloride Pretreatment Experiments*

The average SDI-5 of seawater pretreated with 2, 5,10,15, and 20 ppm $AlCl_3$ was 12.7, 14.2, 15.9, 14.5, and 12.1, respectively (Fig. 4). The best result was obtained with an$AlCl_3$ concentration of 20 ppm (Fig. 4); nevertheless, using the lowest $AlCl_3$ concentration of 2 ppm gave a SDI- 5 close to that of the 20 ppm sample. The SDI-5 results at different $AlCl_3$ concentrationsare displayed in Fig. 4. There is no clear behavior for different concentrations of $AlCl_3$, and using 10 ppm $AlCl_3$ increased the SDI-5 to 15.9.

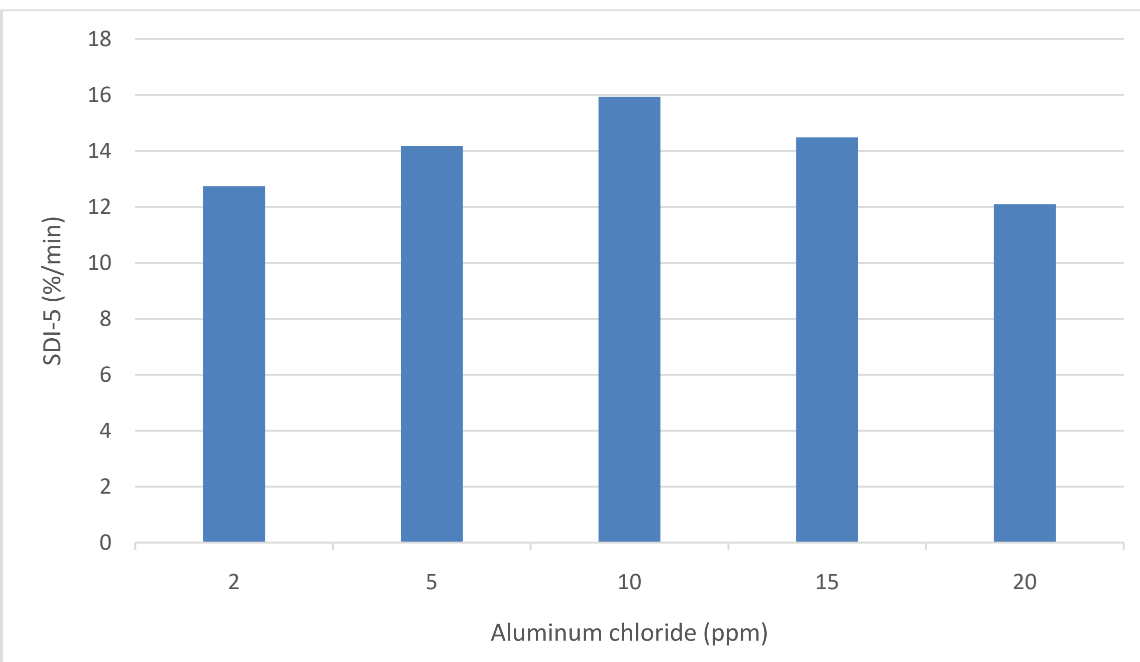

Fig. 4: Effect of pretreatment with aluminum chloride on the SDI-5 of seawater.

IV. Conclusions And Recommendations

The study indicates the important of optimizing the chemical coagulant dose in the pretreatment of seawater for desalination using RO systems. From the three pretreatment chemicals used in this study, i.e., ferric chloride, PAC, and aluminum chloride, ferric chloride gave the best reduction in SDI. The best overall reduction in SDI, 10.05, was obtained with ferric chloride at a concentration of 10 ppm. It is worth noting that a higher SDI was obtained using ferric chloride concentrations of 2, 5, 15, and 20 ppm, which were 15.8, 13.36, 17.99 and 15.30, receptively. It is hypothesized that at low coagulant concentrations, the particles do not sufficiently precipitate, and at higher coagulant concentrations, smaller-sized particles that usually pass through the filter are aggregated to a size sufficient to clog the filter but not large enough to precipitate. This type of behavior is also observed with PAC, where the best reduction in SDI was obtained at a concentration of 10 ppm and at higher and lower PAC concentrations the SDI was higher. It is very clear from the result that the chemical coagulant concentration should be optimized according to the feed seawater quality and that using a higher concentration of chemical coagulant may gave adverse results rather than improving the SDI of the feed seawater.

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