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Desalination of saline water with single and combined adsorbents

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ABSTRACT

Due to high expenses of energy, desalination of saline waters by low-cost methods is important. To investigate the ability of five adsorbents (peat, activated carbon, zeolite, anionic resin, and cationic resin) in single and combined forms to remove salinity ions from aqueous solutions, 21 treatments were prepared for a batch experiment. This study was conducted using 1 g of each adsorbent in 50 cc of saline drainage water with total dissolved solids of $13.32\,\mathrm{g\,L^{-1}}$. The ratios of adsorbents in 1 g of each combined adsorbents were the same. Study results showed that among the single adsorbents, peat and activated carbon with adsorption of 255.5 and 253.7 mg of salinity ions had the highest and lowest adsorption rate, respectively. Zeolite, anionic resin, and cationic resin had the same adsorption rate of salinity ions. Between two and three combined adsorbents, all treatments containing cationic resin had the highest adsorption rate. All adsorbents adsorbed anions about 1.7 times of cations. The main finding of this study was that the highest salinity adsorption occurred in combination of cationic resin with peat, zeolite, activated carbon, and anionic resin. Therefore, application of cationic resin with another adsorbent is much more effective in adsorption of salinity ions as compared to single form or combination of three adsorbents.

Keywords: Single adsorbent; Saline water; Combined adsorbents

1. Introduction

Salinity of irrigation water resources is an important problem in many parts of the world, especially in arid and semiarid regions. Increase of water demand due to population growth will intensify shortage of fresh water in the future. So, usage of unconventional saline and brackish water becomes more important day by day. Although salinity of irrigation water has many destructive effects on crops, but also degradation of soil particles is a common problem in soils irrigated with saline water. It is estimated that about 20% of irrigated lands suffer from salinization induced by irrigation [1]. Desalination is a new technology in water industry; and due to salinity problems in the world, it is predicted to become more important day by day. The most important methods used in desalination process are: thermal distillation as multistage flash, multiple effect, vapor compression, membrane process such as electrodialysis and reverse osmosis (RO), and adsorption process [2,3]. Multistage flash and RO are the most used desalination methods in the world and more than 80% of desalinated water is produced by these processes. The

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major disadvantages of these desalination methods are that they are costly and energy intensive [4,5].

In this study, we attempted to study the effects of five adsorbents (natural zeolite, peat, activated carbon, anionic resin, and cationic resin) in desalination process. Natural zeolites are alumino silicates with a 3-dimensional framework structure bearing AlO_4 and SiO_4 tetrahedral. Due to their high cation exchange ability as well as to the molecular sieve properties, these adsorbents have been widely used in separation and purification processes in the past decades, especially for water and wastewater treatment [6].

Peat is an inexpensive natural substance with lignin, cellulose, and humic materials as its major constituents. The polar character of peat due to polar functional groups such as aldehydes, ketones, carboxylic acid, hydroxylic acid, and phenolic acid has caused good potential for adsorption of metals and polar organic molecules [7,8].

Activated carbon is a commercial product, with high-surface area, microporous character, and high adsorption capacity. This product can be made from various materials that have high carbonaceous content such as wood, coal, petroleum, coke, sawdust, and coconut shell. Activated carbon has high ability in removal of a wide variety of organic and inorganic pollutants and heavy metals from aqueous media [9,10].

Ion exchange resins are organic polymers classified as cation and anion exchangers, with mobile positively and negatively charged ions, respectively. They differ in the ionizable group attached to the hydrocarbon network. Resins can be broadly classified as strong/weak acid cation exchangers or strong/weak anion exchangers.

The objective of this study was comparison of adsorption rate of salinity ions by single and combined forms of five adsorbents.

2. Material and methods

2.1. Adsorbents

This study was conducted using five adsorbents (natural zeolite, peat, activated carbon, anion exchange [anionic] resin, and cation exchange [cationic] resin) in single form and combination of two and three adsorbents. These treatments are listed in Table 1. Characteristics of each adsorbent are described briefly as follows.

2.1.1. Peat

Biolan peat is a product of Biolan Oy Co., Finland, made of raw biomaterials, and used for horticultural

Table 1
Treatments used in this study

Single form	Zeolite		Peat		Activated carbon		Anionic resin		Cationic resin	
	T1		T2		T3		T4		T5	
Combination of two adsorbents	Zeolite + Peat	Zeolite + Activated carbon	Zeolite + Anionic resin	Zeolite + Cationic resin	Peat + Activated carbon	Peat + Anionic resin	Peat + Cationic resin	Activated carbon + Anionic resin	Activated carbon + cationic resin	Anionic resin + cationic resin
	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
Combination of three adsorbents	Zeolite + Peat + Anionic resin	Zeolite + Peat + Cationic resin	Zeolite + Anionic resin + Cationic resin		Activated carbon + Peat + Cationic resin		Peat + Anionic resin + Cationic resin		Activated carbon + anionic resin + cationic resin	
	T16	T17	T18		T19		T20		T21	

Table 2
Some characteristics of activated carbon

Chemical and physical properties					
Solubility	Melting point (°C)	Molar mass ($g\,moL^{-1}$)	Bulk density ($g\,cm^{-3}$)	Particle size (<100μ)	
Insoluble	3,550	12.01	0.15–0.44	About 90%	
Specifications					
Solubility in ethanol	n-Hexane adsorption	SO_4^{2-}	Fe	Pb	Zn
≤0.2%	≥30%	$\leq 100\,mg\,L^{-1}$	$\leq 300\,mg\,L^{-1}$	$\leq 10\,mg\,L^{-1}$	$\leq 10\,mg\,L^{-1}$

purposes. It was dried in an oven for 24 h at 105°C and then passed through a 20-mesh sieve (mesh diameter <0.85 mm). The peat sample was washed for 30 min in 1.0 mol L^{-1} HCl solution by shaking it in an orbital shaker. After washing with HCl, the peat sample was passed through a filter paper and washed with distilled water. The pH of filtrate water was measured continuously until it reached a constant value. The peat sample was then dried in an oven at 60°C for 24 h. Final peat density was about 0.44 g cm^{-3}.

2.1.2. *Activated carbon*

Powdered activated carbon (product number 1021861000) was purchased from Merck Co., Germany. Some of its characteristics are shown in Table 2.

2.1.3. *Natural zeolite*

Natural zeolite was prepared from a mine in Semnan province, I.R. Iran. This material was sieved to pass through a 20-mesh sieve. It was shaked with 1.0 mol L^{-1} HCl for one hour and then was washed with distilled water several times until the pH of filtrate reached a constant value. Then, it was dried in an oven at 80°C for 24 h.

2.1.4. *Cationic resin*

Cationic resin was a synthetic Amberlite IR-120 with the properties presented in Table 3. This hydrogen-formed ion exchange resin was washed with distilled water to remove all the excess acid and then dried at 40°C for 24 h.

Table 3
Properties of Amberlite IR-120

Type	Gel strong acid cation exchange resin
Active group	$-SO_3H$
Matrix	Styrene divinylbenzene copolymer
Ionic form as shipped	H^+
Standard mesh size (wet)	16–45 mesh
Mean particle size	0.5 (mm)
Effective pH range	0–14
Total exchange capacity	1.9 mmol mL^{-1} wet resin

Table 4
Properties of anionic resin

Type	Strong base anion exchanger
Active group	Trimethyl ammonium
Matrix	Styrene divinyl benzene copolymer
Ionic form as shipped	Chloride
Mean particle size	0.600–0.750 mm
Effective pH range	0–14
Total exchange capacity	1.20 mmol L^{-1} (Cl^- form)

2.1.5. *Anionic resin*

Anionic resin was a synthetic Amberlite IRA-402 with characteristics shown in Table 4. To exchange chloride with hydroxide ion of this chloride-formed ion exchange resin, this material was washed with NaOH (1.0 mol L^{-1}) for 1 h in a shaker and was finally washed several times with distilled water until the pH of filtrate reached a constant value. It was then dried at 40°C for 24 h.

2.2. *Adsorbates*

In this study, the main purpose was to determine the ability of mentioned adsorbents in desalination of

Table 5
Saline water characteristics

EC (dS/m)	K	Na	Ca	Mg	Cl	HCO3	SO4
	mg in 50 cc irrigation water						
20.8	0.99	210.6	13.0	10.2	252.9	36.60	141.84

natural saline water with concentration of 13.3 g L^{-1} (EC = 20.8 dS m^{-1}). Table 5 shows characteristics of this saline water.

2.3. Equilibrium studies

In the batch experiments, 1 g of each adsorbent in single form, 0.5 g in combination of two adsorbents, and 0.33 g in combination of three adsorbents was poured in plastic bottles; and 50 mL of saline water was added to each bottle. The bottles were shaken thoroughly in a shaker for 4 h in room temperature (20˚C). Then, the adsorbents were removed from solution using a Watman filter paper and the filtrates were used for further analysis. It should be mentioned that the experiment was a completely randomized design with three replications.

2.4. Concentration measurement

The pH, concentration of chloride (Cl^-), sulfate (SO_4^{2-}), calcium (Ca^{2+}), sodium (Na^+), magnesium (Mg^{2+}), bicarbonate (HCO_3^-), and potassium (K^+), were determined in the primary solution and after removal of the adsorbents from aqueous solutions, using standard analytical procedures [11].

2.5. Data analysis

The difference between mean of measured parameters resulted by different adsorbents in each salinity were compared by Duncan multiple range test at probability level of 5% [SAS [12]].

3. Results and discussion

Tables 6 and 7 show the amount and percent of adsorption of salinity ions by different adsorbents.

3.1. Potassium (K)

Potassium (K) is a nutrient element for plants. As shown in Table 5, initial K concentration was 0.99 mg in 50 cc saline water. Between single adsorbents, cationic resin with adsorption of 62% of initial K concentration (0.6 mg) had the highest adsorption rate. Between combined adsorbents (two adsorbents), application of cationic resin with peat, activated carbon, and anionic resin resulted in the highest K adsorption as much as cationic resin. Between combination of three adsorbents, treatments T19, T20, and T21 had the highest K adsorption. In these treatments, cationic resin was the best adsorbent and peat, activated carbon, and anionic resin ranked next.

3.2. Sodium (Na)

For single form of adsorbents, peat with adsorption of 89.6 mg of initial Na (210.6 mg) was the best. Combination of zeolite, peat, and anionic resin with activated carbon caused the least Na adsorption in double adsorbents. Application of cationic resin with anionic resin and activated carbon had the highest Na adsorption. In triple adsorbents, the highest Na adsorption belonged to cationic resin + zeolite + anionic resin and cationic resin + zeolite + peat treatments. It is important to note that peat, as a natural and cheap adsorbent, has the same Na adsorption as combination of anionic resin and cationic resin, as artificial and expensive adsorbents.

3.3. Calcium (Ca)

Initial Ca dose was 13 mg. In single form, cationic resin and anionic resin with adsorption of 80.8 and 76.9% of Ca had the highest values. In double adsorbents, treatments T9, T12, T14, and T15, which are combination of cationic resin with zeolite, peat, activated carbon, and anionic resin with cationic resin, had satisfactory adsorption rates.

In these treatments, T8 (zeolite + anionic resin) had the highest Ca adsorption (11.5 mg), which is about 88.5% of initial Ca concentration. In triple adsorbents, combination of cationic resin + anionic resin with zeolite (T18), peat (T20), and activated carbon (T21) caused maximum Ca adsorption. It was noticeable that T19 (cationic resin + activated carbon + peat) adsorbed Ca the same as mentioned treatments. Therefore, the highest and the least Ca adsorption belonged to anionic resin + peat (11.5 mg) and activated carbon + peat (4.5 mg), respectively.

Table 6
The amount of adsorption in different treatments

Adsorbents Salinity parameters	K	Na	Ca	Mg	Cl	HCO_3	SO_4	Cations	Anions	Total ions
	mg in 50 cc									
Zeolite	0.0	83.4	6.5	0.6	39.9	25.9	93.4	90.5	159.2	249.7
Peat	0.5	89.6	7.0	1.5	62.1	28.2	66.5	98.6	156.9	255.5
Activated carbon	0.4	77.2	6.0	0.6	39.9	14.5	84.3	84.2	138.7	222.9
Anionic resin	0.5	71.1	10.0	4.8	35.5	21.4	112.7	86.3	169.6	255.9
Cationic resin	0.6	65.0	10.5	9.6	48.8	36.6	68.5	85.7	153.9	239.6
Peat and zeolite	0	78.3	7.0	1.2	44.4	25.2	68.5	86.5	138.0	224.5
Activated carbon and zeolite	0.0	55.3	5.0	0.6	53.3	16.0	0.8	60.9	70.1	131.0
Anionic resin and zeolite	0.1	77.2	11.5	1.2	44.4	0.0	131.4	90.0	175.8	265.8
Cationic resin and zeolite	0.0	77.2	10.0	8.1	35.5	36.4	139.7	95.3	211.8	307.1
Activated carbon and peat	0.5	61.1	4.5	1.8	31.1	26.7	24.1	67.8	81.9	149.7
Anionic resin and peat	0.5	77.2	8.5	3.9	53.3	15.3	85.7	90.1	154.2	244.3
Cationic resin and peat	0.6	77.2	10.5	8.1	39.9	36.3	131.5	96.4	208.0	304.4
Anionic resin and activated carbon	0.5	65.0	7.0	1.8	62.1	6.1	0.9	74.2	69.2	143.4
Cationic resin and activated carbon	0.6	83.4	10.0	8.4	48.8	36.2	133.2	102.4	218.6	321.0
Cationic resin, anionic resin	0.6	89.6	11.0	8.4	64.8	36.1	120.7	109.6	222.1	331.7
Anionic resin, peat, and zeolite	0.1	56.5	8.5	1.5	22.2	13.7	65.4	66.6	101.3	167.9
Cationic resin, peat, and zeolite	0.1	72.6	8.5	5.4	31.1	36.6	103.7	86.6	171.4	257.9
Cationic resin, anionic resin, and zeolite	0.1	79.5	11.0	5.7	57.7	36.6	75.0	96.3	169.3	265.6
Cationic resin, activated carbon, and peat	0.6	38.1	10.0	6.6	22.2	36.6	1.6	55.2	60.4	115.6
Cationic resin, anionic resin, and peat	0.6	63.4	11.0	5.4	31.1	36.6	78.4	80.3	146.1	226.4
Cationic resin, anionic resin, and activated carbon	0.6	65.0	10.0	7.8	22.2	36.6	123.6	83.4	182.4	265.8

3.4. Magnesium (Mg)

Although the initial concentration of Mg was approximately the same as Ca, but the adsorption of Mg by all adsorbents was less than Ca. In single adsorbents, cationic resin adsorbed Mg (9.6 mg) much more than others. The least Mg adsorption belonged to zeolite and activated carbon. Combination of cationic resin with zeolite, peat, and activated carbon reduced Mg adsorption about 15.6, 15.6, 12.5, and 12.5%, respectively, as compared to cationic resin. The Mg adsorption by zeolite, peat, activated carbon, and anionic resin was highest when applied with cationic resin.

3.5. Chloride (Cl)

About 38% of salinity ions was Cl. Peat adsorbed more Cl as compared to zeolite, activated carbon, anionic resin, and cationic resin. This material adsorbed about 25% of initial Cl (62.1 mg). It is important that anionic resin adsorbed Cl less than peat, cationic resin and zeolite as cation exchangers. It is so important that only application of cationic and cationic resin caused more Cl adsorption (64.8 mg) as compared to peat, and application of anionic resin with peat resulted in the same Cl adsorption as compared to peat. Other combined adsorbents had less Cl adsorption as compared to peat.

3.6. Bicarbonate (HCO_3)

Bicarbonate is the only element which was adsorbed completely by some adsorbents. These adsorbents are cationic resin, cationic resin + zeolite, cationic resin + peat, cationic resin + activated carbon, and cationic resin + anionic resin and all treatments with three adsorbents except anionic resin + peat + zeolite. Therefore, in all treatments with cationic resin,

Table 7
The percent of adsorption in different treatments

Adsorbents Salinity parameters mg in 50 cc	K	Na	Ca	Mg	Cl	HCO3	SO4	Cation	Anion	Total ion
Zeolite	0	39.6	50.0	5.9	15.8	70.8	0.66	38.5	36.9	37.5
Peat	51	42.5	53.8	14.7	24.6	77.1	0.47	42.0	36.4	38.3
Activated carbon	43	36.7	46.2	5.9	15.8	39.6	0.59	35.9	32.2	33.5
Anionic resin	46	33.8	76.9	47.1	14.0	58.3	0.79	36.8	39.3	38.4
Cationic resin	62	30.9	80.8	94.1	19.3	100.0	0.48	36.5	35.7	36.0
Peat and zeolite	0	37.2	53.8	11.8	17.5	68.8	0.48	36.8	32.0	33.7
Activated carbon and zeolite	0	26.3	38.5	5.9	21.1	43.8	0.01	25.9	16.3	19.7
Anionic resin and zeolite	7	36.7	88.5	11.8	17.5	0.0	0.93	38.3	40.8	39.9
Cationic resin and zeolite	1	36.7	76.9	79.4	14.0	100.0	0.98	40.6	49.1	46.1
Activated carbon and peat	46	29.0	34.6	17.6	12.3	72.9	0.17	28.9	19.0	22.5
Anionic resin and peat	53	36.7	65.4	38.2	21.1	41.7	0.60	38.4	35.7	36.7
Cationic resin and peat	60	36.7	80.8	79.4	15.8	100.0	0.93	41.1	48.2	45.7
Anionic resin and activated carbon	46	30.9	53.8	17.6	24.6	16.7	0.01	31.6	16.0	21.5
Cationic resin and activated carbon	60	39.6	76.9	82.4	19.3	100.0	0.94	43.6	50.7	48.2
Cationic resin and anionic resin	60	42.5	84.6	82.4	25.6	100.0	0.85	46.7	51.5	49.8
Anionic resin, peat, and zeolite	14	26.8	65.4	14.7	8.8	37.5	0.46	28.4	23.5	25.2
Cationic resin, peat, and zeolite	11	34.5	65.4	52.9	12.3	100.0	0.73	36.9	39.7	38.7
Cationic resin, anionic resin, and zeolite	14	37.7	84.6	55.9	22.8	100.0	0.53	41.0	39.2	39.9
Cationic resin, activated carbon, and peat	58	18.1	76.9	64.7	8.8	100.0	0.01	23.5	14.0	17.4
Cationic resin, anionic resin, and peat	58	30.1	84.6	52.9	12.3	100.0	0.55	34.2	33.9	34.0
Cationic resin, anionic resin, and activated carbon	58	30.9	76.9	76.5	8.8	100.0	0.87	35.5	42.3	39.9

HCO_3 was adsorbed completely. The least HCO_3 adsorption belongs to combination of anionic resin with zeolite and activated carbon (0 and 16.7%), respectively.

3.7. Sulfate (SO^4)

In single adsorbents, the highest SO4 adsorption was about 112.7 mg happened by anionic resin. Combination of adsorbents in five treatments of anionic resin + zeolite, cationic resin + zeolite, cationic resin + peat, cationic resin activated carbon, and cationic resin + anionic resin resulted higher adsorption as compared to anionic resin and in other treatments with two adsorbents the adsorption rate was lower than anionic resin. In treatments of three adsorbents, only application of anionic resin + cationic resin + activated carbon with adsorption of 123.6 mg SO4 adsorption resulted higher SO4 adsorption as compared to anionic resin.

3.8. Anions and cations

Initial concentration of anions and cations was 431.3 and 234.8 mg, respectively. Therefore, the anions concentration was about 1.84 times of cations concentration. Due to the higher concentration of anions, in all treatments, adsorption of anions was much more than cations (approximately 1.7 times). The highest cation adsorption belongs to peat and zeolite; activated carbon, anionic resin, and cationic resin had the same cation adsorption rate. It is important that peat and zeolite as natural adsorbents had higher cation adsorption as compared to cationic resin as an artificial adsorbent. The highest anion adsorption belongs to anionic resin, with adsorption of 169.6 mg anion; and zeolite, peat, and cationic resin had the same anion adsorption rate. Activated carbon had the least anion adsorption. Combination of cationic resin with zeolite, peat, activated carbon, and anionic resin effectively improved anion adsorption rate about 37.6, 35.2, 42, and 44.3%, respectively.

Application of anionic resin with zeolite and cationic resin increased anion adsorption about 3.7 and 31%, and in the case of peat and activated carbon, adsorption rate reduced about 9.1 and 59.2%, respectively. Adsorption of cations by double adsorbents shows that only in application of cationic resin with activated carbon and anionic resin, the adsorption rate of cations was higher than maximum cations adsorbed by single adsorbents (98.6 mg). In triple adsorbents, maximum cations and anions adsorption was 96.3 and 182.4 by cationic resin + anionic resin + zeolite and cationic resin + anionic resin + activated carbon, respectively. Therefore, maximum cations and anions adsorption between all treatments belongs to combination of cationic and anionic resin adsorbing 46.7 and 51.5% of cations and anions, respectively.

3.9. Total ions

In 50 cc of saline water, total salinity ions was about 666.1 mg. Between single adsorbents, activated carbon with adsorption of 222.9 mg of salinity ions had the least salinity ion adsorption. It is so important that adsorption rate of salinity ions by peat and zeolite, as cheap and natural adsorbents, is equal to adsorption rate of anionic resin and cationic resin, as commercial and expensive adsorbents. Adsorption by zeolite, peat, activated carbon, anionic resin, and cationic resin was about 37.5, 38.3, 33.5, 38.4, and 36%, respectively. In double adsorbents, the highest adsorption rate belongs to combination of anionic resin with cationic resin, which caused salinity ions adsorption of 331.7 mg (about 49.8% of initial salinity ions). Whatever anionic resin adsorbed about 38.4% and cationic resin adsorbed about 36% of salinity ions, but combination of these adsorbents increased salinity ions adsorption of anionic and cationic resin about 11.4 and 13.8%, respectively. It is important that combination of cationic resin with zeolite, peat, and activated carbon caused adsorption of 57.5, 64.8, and 81.4 mg more than adsorption by cationic resin in single form. In the case of peat, combination of this adsorbent with zeolite, activated carbon, and anionic resin caused less salinity ions adsorption as compared to peat in single form. Application of zeolite with cationic and anionic resin caused more adsorption as compared to zeolite in single form, but combination of zeolite with peat and activated carbon resulted in less adsorption. In the case of activated carbon, only application of cationic resin with this adsorbent caused more adsorption than activated carbon in single form. Application of activated carbon with zeolite, peat, and anionic resin caused the least adsorption. Combination of three adsorbents resulted in less adsorption as compared to combination of two adsorbents. In combination of two adsorbents, treatment of anionic resin + cationic resin had the highest adsorption, but application of zeolite, peat, and activated carbon caused adsorption rate reduction about, 11.1, 15.8 and 9.9%, respectively. Therefore, application of cationic resin with peat, zeolite, activated carbon, and anionic resin resulted in the highest salinity adsorption among all the adsorbents.

4. Discussion

To find the main adsorption process for each adsorbent, Figs. 1–3 are presented. Zeolite, peat, and cationic resin are cation exchangers. Before the study, the main exchangeable cation of these adsorbents was hydrogen (H) ion. As they adsorbed cations (K, Na, Ca, and Mg), released H in solution resulted in pH reduction. Initial pH of saline water was about 8.49. Therefore, as shown in Fig. 1, the reduction of solution pH by these adsorbents means that these adsorbents have adsorbed cation-by-cation exchange mechanism. Anionic resin is an anion exchanger, caus-

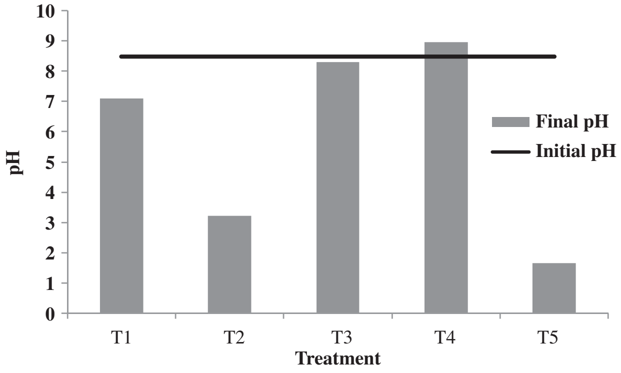

Fig. 1. Initial and final pH of saline water due to application of single form adsorbent.

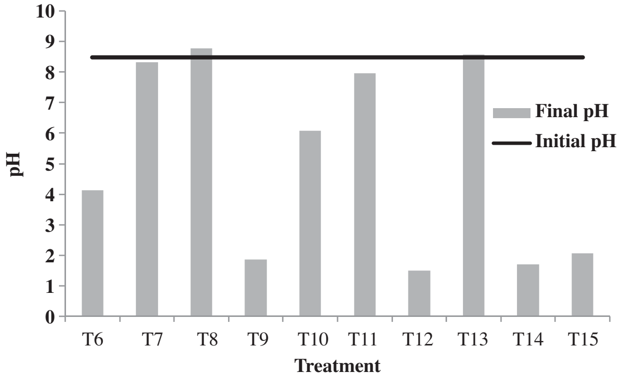

Fig. 2. Initial and final pH of saline water due to application of combination of two adsorbents.

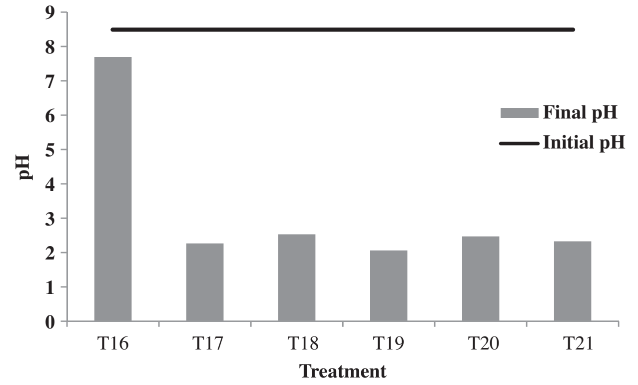

Fig. 3. Initial and final pH of saline water due to application of combination of three adsorbents.

ing an increase in solution pH due to adsorption of anion and releasing hydroxide (OH) ions in solution. Activated carbon does not have significant effect on solution pH. In the case of anionic resin, final solution pH has increased and this increase is very low. As shown in Fig. 2, the final pH of treatments with cationic resin has decreased significantly (T9, T12, T14, and T15). In treatments of T6, T10, and T11, due to presence of peat, the final pH has reduced too. Only in treatments of T7, T8, and T13, pH has not changed during the experiment. Therefore, the more pH reduction resulted in more cation adsorption. As presented in Fig. 3, in all treatments with cationic resin (T17, T18, T19, T20, and T21), initial pH has reduced significantly. Therefore, in all treatments with cationic resin pH reduction has occurred, and the main adsorption process is cation exchange. In the case of zeolite and peat, the adsorption process is due to cation exchange and surface adsorption; and the main process for activated carbon is high-surface attraction of this adsorbent [13]. As shown in this study in treatments with high cation adsorption, anion adsorption is high too. This process is due to cation bridge mechanism by adsorbed cations [14].

5. Conclusions

This study was conducted to investigate the ability of adsorption of salinity ions by two natural adsorbents (zeolite and peat) and three artificial adsorbents (activated carbon, anionic resin, and cationic resin) in single and combined forms. The results showed that all HCO_3 ions were adsorbed by some adsorbents completely. In all treatments, adsorption of anions was much more than cations. Maximum cation and anion adsorptions belonged to combination of cationic and anionic resins adsorbing 46.7 and 51.5% of cations and anions, respectively. For single form adsorbents, peat and activated carbon with adsorption of 255.5 and 253.7 mg of salinity ions had the highest and lowest adsorption rate, respectively. Zeolite, anionic resin, and cationic resin had the same adsorption rate of salinity ions. The adsorption rate of salinity ions by peat and zeolite, as cheap and natural adsorbents is equal to adsorption rate of anionic resin and cationic resin, as commercial and expensive adsorbents. The highest adsorption rate of salinity ions belonged to combination of anionic resin with cationic resin, which caused salinity ions adsorption of 331.7 mg (about 49.8% of initial salinity ions). Combination of cationic resin with peat, zeolite, activated carbon, and anionic resin resulted in the highest salinity ions adsorption between all treatments and application of cationic resin with another adsorbent (double combination) was much more effective in adsorption of salinity ions as compared to single form or triple adsorbents.

References

[1] S. Wood, K. Sebastian, S.J. Scherr, Soil Resource Condition. in: Pilot Analysis of Global Ecosystems (PAGE), IFPRI and World Resources Institute, Washington, pp. 45–54 2000.

[2] A.M. Ahmed, I. Moch, Seawater reverse osmosis, Desalination IS3 (2002) 265–272, 272 A.J. Databank, M.A. Al-Nimr.

[3] Y.M. Kim, S.J. Kim, Y.S. Kim, S. Lee, I.S. Kim, J.H. Kim, Overview of systems engineering approaches for a large-scale seawater desalination plant with a reverse osmosis network, Desalination 238 (2009) 312–332.

[4] G.K. Pearce, UF/MF pre-treatment to RO in seawater and wastewater reuse applications: A comparison of energy costs, Desalination 222 (2008) 66–73.

[5] L.C. Lin, J.K. Li, R.S. Juang, Removal of Cu(II) and Ni(II) from aqueous solutions using batch and fixed-bed ion exchange processes, Desalination 225 (2008) 249–259.

[6] S. Wang, Y. Peng, Natural zeolites as effective adsorbents in water and wastewater treatment, Chem. Eng. J. 156 (2010) 11–24.

[7] K. Yonebayashi, J. Pechayapisit, P. Vijarnsorn, A.B. Zahari, K. Kyuma, Chemical alterations of tropical peat soils determined by Waksman's proximate analysis and properties of humic acids, Soil Sci. Plant Nutr. 40 (1994) 435–444.

[8] F. Qin, B. Wen, X.Q. Shan, Y.N. Xie, T. Liu, S.Z. Zhang, S.U. Khan, Mechanisms of competitive adsorption of Pb, Cu, and Cd on peat, Environ. Pollut. 144 (2006) 669–680.

[9] O. Gercel, H.F. Gercel, Adsorption of lead (II) ions from aqueous solutions by activated carbon prepared from biomass plant material of *Euphorbia rigida*, Chem. Eng. J. 132 (2007) 289–297.

[10] Y. Zeng, H. Woo, G. Lee, J. Park, Adsorption of Cr(VI) on hexadecylpyridinium bromide (HDPB) modified natural zeolites. Micropor, Mespor. Mat. 130 (2010) 83–91.

[11] A.E. Greenberg, L.S. Clasceri, A.D. Eaton, Standard Methods for the Examination of Water and Wastewater, APHA, AWWA and WPCF, Washington, DC, 1992.

[12] SAS Institute, SAS/STAT Users Guide, SAS Institute, Cary, NC, 1999.

[13] S.A. Dastgheib, D.A. Rockstraw, A model for the adsorption of single metal ion solutes in aqueous solution onto activated carbon produced from pecan shells, Carbon 40 (2002) 1843–1851.

[14] J.B. Xiong, Q. Mahmood, Adsorptive removal of phosphate from aqueous media by peat, Desalination 259 (2010) 59–64.