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Development of Filtration System using Chitosan and Silica Sand as Adsorbents for Reducing Salinity of Water for Micro-Irrigation

Amarpreet Singh[2], Sunil Garg[1]*, Mukesh Siag[1] and Ritesh Jain[3]

[1]*Deptt. of Soil & Water Engineering, Punjab Agricultural University, Ludhiana-141004, Punjab, India*
[2]*Ex-Student, Deptt. of Soil & Water Engineering, Punjab Agricultural University, Ludhiana-141004, Punjab, India*
[3]*Deptt. of Civil Engineering, Punjab Agricultural University, Ludhiana-141004, Punjab, India*
**Corresponding author E-mail: sunil1765@pau.edu*

Abstract

A study was conducted to develop filtration technique by using chitosan and silica sand as adsorbents for reducing salinity of water for irrigation purpose. Chitosan is biopolymer which is extracted by alkaline deacetylation (40–50% NaOH) of chitin. It is an abundant natural biopolymer obtained from the exoskeletons of crustaceans and arthropods which is a non-toxic copolymer consisting of b-(1,4)-2-acetamido-2-deoxy-Dglucose and b-(1,4)-2-anaino-2-deoxy-D-glucose units. The chitin is produced after crushed, washed and demineralized with 1N HCL from shrimp shell. It is widely used in agricultural fields, medicinal and removal of inorganic contaminants (e.g. trace metals) from wastewater and soil. Silica sand is also known as quartz sand and is produced from quartz stone by crushing. It is mainly the compound of silicon and oxygen and is used for adsorption purposes and glass making factories. Nanoporous silica materials have great applications in catalysis, separation and wastewater treatment because of their large surface areas, narrow pore size distribution and high adsorption capacities. The adsorbent chitosan and silica sand was able to reduce electrical conductivity (EC) by approx. 24% and 12% respectively. Optimum contact time for both adsorbents was found out to be 30 minutes.

Key words: Filtration system, Chitosan, Silica sand, Adsorbent, Electrical conductivity, Contact time

Introduction

Water is one of the significant inexhaustible assets that support life. As the population of India is growing, the use of water is also expanding at a fast pace. The significance of the groundwater resource in India can be realized by the fact that about 50% of the total irrigated area is dependent upon groundwater and about 60% of irrigated food production depends on irrigation from groundwater wells (Singh and Singh, 2002). Considerable part of groundwater in various Indian states has been reported either saline or sodic (Minhas, 1996). Sodicity and/or salinity are regular problems under irrigated agriculture particularly in areas of low precipitation and high requirement (Sumner, 1993). The saline concentration due to irrigation by saline water results in reducing soil porosity, soil permeability and hydraulic conductivity (Tedeschi and Dell'Aquila, 2005). Higher values of sodium adsorption ratio (SAR) of saline water irrigation results in clay dispersion, decreased aggregate stability, surface crusting, swelling of expandable clays and reduced tilth (Suarez *et al.,* 2006). The groundwater in many parts of southwest Punjab contains high pH (7.5-8.4), high concentration (700-2000 ppm) of dissolved salts with electrical conductivity of 1200-1600 $\mu S\ cm^{-1}$ (Sharma *et al.,* 2013).

Filtration is a common but effective process for treatment of water in comparison with other desalination technologies. A number of desalination technologies have been created on the basis of electro dialysis, membrane separation, thermal distillation, multistage flash (MSF) method, freezing, reverse osmosis (RO) etc. But these technologies are costly for agricultural use. For agricultural purposes there is a great requirement for simple and low-cost techniques for reducing water salinity (Wajima, 2013). Adsorption is right and inexpensive method for desalination for agriculture point of view. The adsorbent materials with high specific surface area made up of agricultural waste such as rice husk, coconut shells etc. Adsorption was recognized to be inexpensive and efficient for eliminating heavy metal ions, organic contaminants, and dyes from effluent waters (Imamoglu and Tekir, 2008). Many adsorbents like silica sand, activated carbon and graphene can be used for treatment of water (Tangjuank *et al.,* 2009). Activated carbon has proven for better adsorbent for the removal of organic and inorganic pollutants from aquifer water. Because of its large surface areas that varied from 500 to 1500 m^2 g^{-1} it is broadly used in the purification of water (Karnib *et al.,* 2014). The Adsorption is surface phenomenon and by this the salts are accumulated on surfaces of adsorbent. As a result, the EC and SAR values are reduced. Nasrullah *et al.* (2021) conducted experiment to prepare activated carbon from mangosteen peels (MP) waste and investigate the effect on activated carbon by adsorption of cationic methylene blue from ionic solution. Ball milled activated carbon (BMAC) was prepared by milling process of short period of 30 minutes at 350 revolutions per minute.

However, to irrigate crops with saline water of certain salt content after treatment, it is necessary to use special arrangements to apply water on field. This issue can be overcome by applying saline water through filtration strategy by using micro-irrigation system. In now days' drip irrigation, a type of micro irrigation is widely considered as the best suitable irrigation technology to use saline water of certain salt content. Various points contribute to the better performance acquired with saline water irrigation by use of drip irrigation: (i) prevent salt accumulation due to less supply of water (ii) prevent leaf burn (iii) high-frequency drip irrigation avoid the soil from drying out between irrigation events, so preventing peaks in salt concentration and concomitant high osmotic potentials (iv) salts of applied irrigation water are leaching continuously away from the wetted region and accumulate at the wetting front away from the active root zone (Nangare *et al.,* 2013).

So, the present study will examine the effectiveness of using chitosan and silica sand as an environmental-friendly adsorbent combined with micro-irrigation system will give better solution of saline water problem in affected areas. The information on development of filtration system by using chitosan and silica sand for reducing salinity for micro-irrigation is limited.

Materials and Methods

Selection of adsorbents

The adsorbents used in the study were chitosan and silica sand which were capable to improve quality of water by reducing salinity. The chitosan flakes were obtained from Marine hydrocolloids located at Kerala. These flakes were further processed in hammer mill for obtain desirable size of 0.75-1.18 mm. Silica sand used in this study was obtained from Research Farm of Department of Soil and Water Engineering, PAU.

Water quality criteria

The parameters used for determination of quality of irrigation water are as follows:

Electrical conductivity (EC)

Electrical conductivity of water is the ability of water to conduct the electric current. Salts and other chemicals are dissolved in water. The salts present in water are in form of suspended ions. These ions are positively and negatively charged.

In this study, the electrical conductivity was measured by digital instrument HANNA HI98130 as shown in Fig.2.

pH

The definition of pH is that it is a proportion of the movement of the hydrogen particle (H^+) and is accounted for as the equal of the logarithm of the hydrogen particle. As the water with a pH of 7 has 10-7 moles for every litre of hydrogen particles. This parameter is used to measure the acidity or basicity of irrigation water (less than 7.0 acidic and greater than 7.0 is basic). The normal range for pH in surface water is 6.5 to 8.5 and for groundwater 6 to 8.5.

Simulated saline water (SSW)

Simulated saline water was prepared by dissolving calculated amount of sodium chloride salt in water to get desired electrical conductivity (EC) of 5.0 dS m^{-1}.

Adsorption technique

Adsorption is surface phenomenon in which adsorbents adsorb materials, ions and substances to their surface. The particles which adsorb on surface of adsorbent are called adsorbate. Adsorption was performed by batch and column method.

Batch adsorption studies

In batch studies, orbital shaker was used for adsorption. 5, 10, 20, 30 gms of each adsorbent with 100 ml of saline water was poured in 250 ml Erlenmeyer flask and agitated on orbital shaker for 30 minutes at 60 revolutions per minute Aghakhani *et al.* (2013). The treated water was then filtered through Whatman filter paper and collected for quality analysis.

Column adsorption studies

Column studies were performed in a special developed container which was fabricated by a acrylic sheet. The dimension of container is 30 cm × 20 cm × 12 cm. The container consist of three parts as shown in Fig.1. The material container is filled with adsorbent. The simulated saline water is filled in the reservoir tank and the adsorbent is allowed to remain in contact with simulated saline water for known time. The treated water is then filtered and value of electrical conductivity is noted.

Treatments

The five contact time treatments were selected as 1, 15, 30, 60 and 120 minutes with three replications.

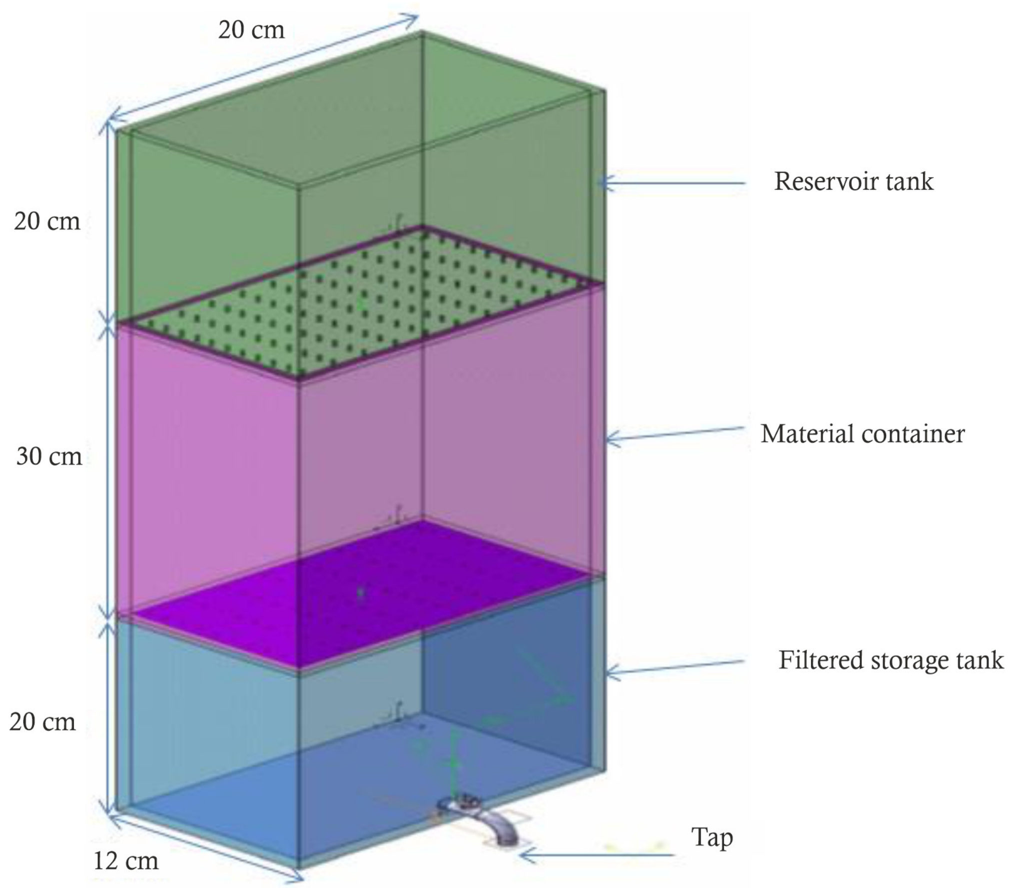

Fig. 1 Fabrication of container for column studies

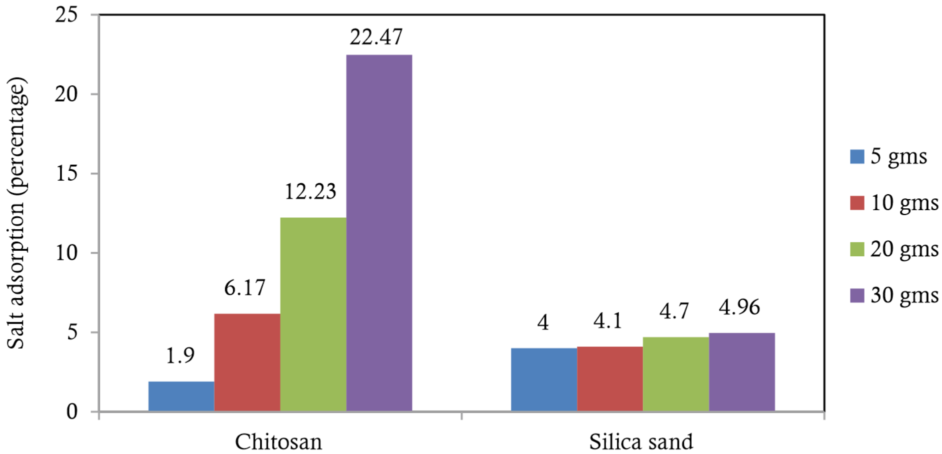

Fig. 2 Adsorbents based on batch method

Statistical analysis

The data collected from the lab experiments were subjected to statistical analysis using O.P. Sheoren Programmer developed by Computer Section, CCS HAU, Hisar. The data was statistically analysed using analysis of variance (ANOVA) techniques. The significance of differences was tested at 5 percent level.

Life cycle assessment of adsorbents.

Life cycle assessment of adsorbents chitosan and silica sand was carried out in the laboratory to see that for how many cycles or reuse adsorbents can be used maintaining almost same adsorption capacity. For this simulated saline water of known electrical conductivity was passed through adsorbent chitosan of known quantity based on batch method for optimum contact time. Same procedure was followed for batch method to find salt adsorption.

Similarly, to find life cycle of adsorbent silica sand based on column method same procedure was followed for column method to find salt adsorption.

Performance evaluation of developed filtration technique using drip irrigation

Filtration technique developed basically is a combination of batch and column method. Chitosan and silica sand was used as an adsorbent for batch and column methods respectively. Performance evaluation of developed filtration technique was carried out in two parts. First part is to find the quantity of chitosan required for desalination of known quantity of water. For this 3 kg of chitosan was taken and mixed in 10 litres of simulated saline water. The mixture was stirred continuously with the help of impeller for 60 minutes. The value of electrical conductivity (EC) was noted at different time intervals.

Results and Discussion

Adsorption by batch method

Salt adsorption by taking 5, 10, 20 and 30 grams of chitosan and silica sand

5, 10, 20 and 30 grams of chitosan and silica sand were mixed with 100 ml of simulated saline water filled in different Erlenmeyer flasks and rotated in orbital shaker for 30 min at 60 revolutions per minute. After this process the treated water was filtered through Whatman filter paper and the values of electrical conductivity (EC) and pH of water were noted by using digital instrument. Results of which are shown in Fig. 2. From the figure, it was clear that as the quantity of adsorbent is increased from 5 to 30 gms, salt adsorption increases from 1.9% to 22.47% respectively for adsorbent chitosan and 4% to 4.96% for silica sand.

Adsorption by column method

In this method simulated saline water was passed through glass container filled with adsorbent up to a height of 20 cm with contact period of thirty minutes. The treated water was then filtered through Whatman filter paper and the values of

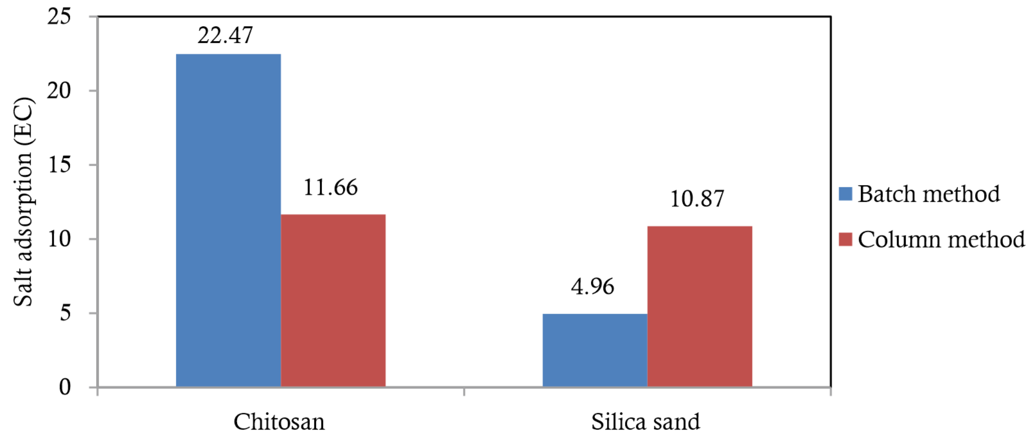

Fig. 3 Percentage of salt adsorption (EC) by adsorbents using batch and column method

electrical conductivity and pH of water were noted.

Selection of adsorbents and adsorption method for detailed adsorption studies

Selections of adsorbents using batch and column method were compared for selection of adsorption method and adsorbents for further studies as shown in Fig. 3. It was clear from Fig. 3 that both batch and column method showed better results. It was decided that chitosan will be used as adsorbent for batch method and silica sand adsorbent for column method.

Optimum contact time for adsorption by chitosan

Adsorbent chitosan was tested for determination of optimum contact time. The simulated saline water was passed through adsorbent with different contact time of 1 min, 15 min, 30 min, 60 min and 120 min respectively. Treated water was then filtered through Whatman filter paper and tested for electrical conductivity present in each sample as shown in Fig. 4. The results showed that after 30 minutes there was instant decrease in electrical conductivity from 5.0 dS m^{-1} to 3.57 dS m^{-1}. So optimum contact time for adsorbent chitosan was taken as 30 minutes asthe electrical conductivity after 30, 60 and 120 minutes was almost same. Statistical test of analysis of variance (ANOVA) design of CRD test was applied to see the significance of electrical conductivity on contact time as shown in Table 1 and Table 2. The relationship between EC and adsorbent showed a good correlation of R^2 = 0.919 and it followed a quadratic relationship. From the Table 1, the value of electrical conductivity and contact time significantly effect on each other. From the Table 2, critical difference (C.D.) is 0.100. Treatment

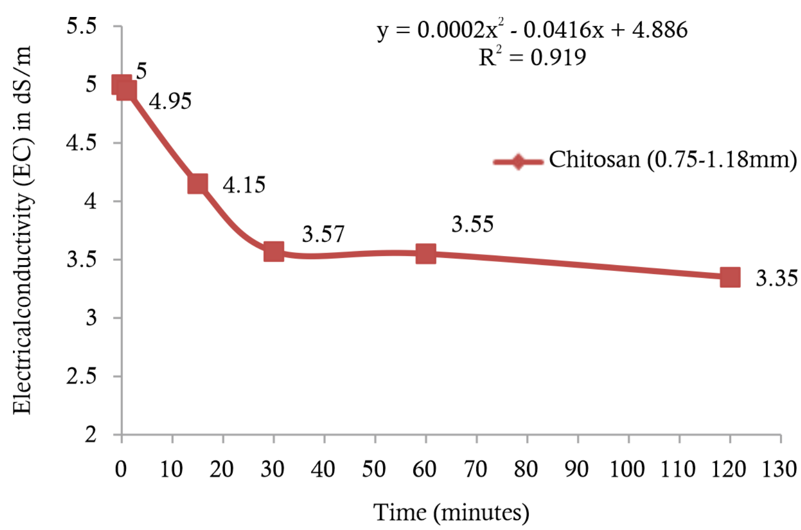

Fig. 4 EC of water by adsorbent chitosan using batch method for different contact time

Table 1. Analysis of Variance Table

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Treatment	4	5.094	1.273	430.143	0.00000
Error	10	0.030	0.003		
Total	14	5.123			

Table 2 Critical difference, standard errors and mean

Treatment	Chitosan	
	Mean	S.E
1	4.950	0.021
2	4.150	0.015
3	3.570	0.050
4	3.550	0.021
5	3.350	0.036
C.D.	0.100	
SE(m)	0.031	
SE(d)	0.044	
C.V	1.390	

(T1) is significantly different from treatment (T2) as their mean difference is more than critical value.(T1-T2 i.e 4.950-4.150 = 0.8 >0.100) But treatment T3 is not significantly differ from T4 as their mean difference 0.02 is less than calculated critical value. So, the optimum contact time was taken as 30 minutes.

Optimum contact time for adsorption by silica sand

Optimum contact time for adsorption of silica sand was carried out by passing simulated saline water for contact time of 1, 15, 30, 60 and 120 minutes. Treated water was filtered and tested for EC as shown in Fig. 5. The results showed that after 30 minutes there was instant decrease in electrical conductivity from 5.0 dS m^{-1} to 4.50 dS m^{-1}. So optimum contact time for adsorbent silica sand was taken as 30 minutes as the electrical conductivity after 30, 60 and 120 minutes was almost same. Statistical test of analysis of variance (ANOVA) design of CRD test was applied to see the significance of electrical conductivity on contact time as shown in Table 3 and Table 4. The relationship between EC and adsorbent showed a good correlation of $R^2 = 0.955$ and it followed a quadratic relationship. From the Table 3, the value of electrical conductivity and contact time significantly effect on each other. From the Table 4, the critical difference (C.D) value was calculated as 0.107. The treatment (T1) is significantly different from treatment (T2), (T3), (T4) and (T5) as their mean difference is greater than critical difference. But treatment (T3) and treatment (T4) are not significantly different. So, the optimum contact time for silica sand for treatment was taken as 30 minutes.

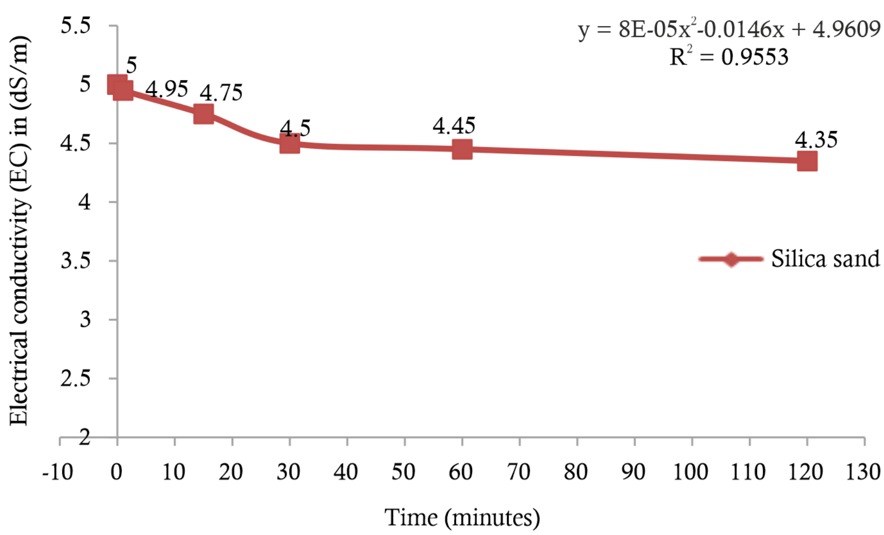

Fig. 5 EC of water by adsorbent silica sand using column method for different contact time

Table 3. Analysis of Variance Table

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Treatment	4	0.720	0.180	53.255	0.00000
Error	10	0.034	0.003		
Total	14	0.754			

Table 4. Critical difference, standard error and mean

Treatment	Silica sand	
	Mean	S.E
1	4.950	0.015
2	4.750	0.021
3	4.500	0.046
4	4.450	0.051
5	4.350	0.015
C.D.	0.107	
SE(m)	0.034	
SE(d)	0.047	
C.V	1.264	

Life cycle assessment of adsorbents

Life cycle assessment of adsorbent chitosan and silica sand were found out.

Life cycle assessment of adsorbent chitosan

Life cycle assessment of chitosan was found out as shown in Table 5. One life cycle was taken as 30 minutes which was optimum contact time found out in batch method. From the table it was clear that after using adsorbent chitosan for six life cycles, the salt adsorption varied from 23.20% to 20.50%. After seventh life cycle, the salt adsorption reduced to 15.89% (EC: 3.65 dS m^{-1}) from 23.20% (EC: 3.35 dS m^{-1}). So, it can be concluded that adsorbent chitosan from batch studies can be reused for 6 life cycles (180 min). The same chitosan material was then washed out to remove salts adsorbed on their surface by tap water. Now, the washout chitosan can be again reused to reduced electrical conductivity.

Life cycle assessment of adsorbent silica sand

Life cycle assessment of adsorbent silica sand was found out as shown in Table 6. One life cycle was taken as 30 minutes which was optimum contact time found out in column method. From the table it was clear that after using adsorbent silica sand for six life cycles, the salt adsorption varied from 13.50% to 9.33%. After seventh life cycle, the salt adsorption reduced to 8.24% from 13.50%. So, it can be concluded that adsorbent silica sand can be reused for 6 life cycles (180 min). The same silica sand material was then washed out to remove salts adsorbed on their surface by tap water. Now, the washout silica sand can be again reused to reduced electrical conductivity.

Performance evaluation of developed filtration technique for drip irrigation system

First part is to find the quantity of chitosan required for desalination of known quantity of water. For this 3 kg of chitosan was taken and mixed in 10 litres of simulated saline water in tank. The mixture was stirred continuously with the help

Table 5. Life cycle assessment of adsorbent chitosan

S. No.	Cycles	Contact time (min)	Cumulative Contact time (min)	EC (dS m^{-1}) (initial)	EC (dS m^{-1}) (final)	Salt Adsorption percentage
1	1	30	30	4.34	3.33	23.20
2	2	30	60	4.34	3.34	23.0
3	3	30	90	4.34	3.35	22.81
4	4	30	120	4.34	3.38	22.0
5	5	30	150	4.34	3.43	20.96
6	6	30	180	4.34	3.45	20.50
7	7	30	210	4.34	3.65	15.89

Table 6. Life cycle assessment of adsorbent silica sand

S. No.	Cycles	Contact time (min)	Cumulative contact time (min)	EC (dS m^{-1}) (initial)	EC (dS m^{-1}) (final)	Salt Adsorption percentage
1	1	30	30	6.43	5.56	13.50
2	2	30	60	6.43	5.66	11.97
3	3	30	90	5.30	4.69	11.50
4	4	30	120	6.43	5.73	10.80
5	5	30	150	5.30	4.77	10.00
6	6	30	180	6.43	5.83	9.33
7	7	30	210	6.43	5.90	8.24
8	8	30	240	6.65	6.18	7.06
9	9	30	270	8.30	7.72	6.98
10	10	30	300	8.30	7.73	6.86

Table 7. Salt adsorption (EC) at different contact time using batch method

S. No.	Adsorbent	Contact time (minutes)	EC (initial) (dS m^{-1})	EC (final) (dS m^{-1})	Salt adsorption (Percent)
1	Chitosan(0.75-1.18mm)	10	5.0	4.6	8.0
2	Chitosan(0.75-1.18mm)	15	5.0	4.4	12.0
3	Chitosan(0.75-1.18mm)	30	5.0	3.8	24.0
4	Chitosan(0.75-1.18mm)	60	5.0	3.8	24.0

of impeller for 60 minutes. Performance evaluation of developed filtration system was carried out in the field using drip irrigation system.The value of electrical conductivity (EC) was noted at different time intervals as shown in Table 7. The results showed that as the contact time for adsorbent is increased from 10 min to 60 min, EC decreases from 8% to 24% respectively. EC at contact time for 30 minutes and 60 minutes is same. So, contact time of 30 minutes for salt adsorption can be taken as optimum contact time which is same contact time for results shown in Table 7.

Treated water of known EC (3.8 dS m^{-1}) was then passed through the drip filter already containing silica sand as shown in Fig. 6. The results obtained are shown in Table 8. The contact time in sand filter is managed by valve attached to the bottom of filter. The valve was opened when the contact period of desired time was fulfilled and was used for irrigation

The results showed that as the contact period of time for adsorbent is increased from 10 min to 60 min, EC decreases from 4.0% to 13% respectively. Electrical conductivity (EC) at contact time for 30 and 60 minutes is nearly same. So, contact time of 30 minutes is optimum time for salt adsorption technique. Further it is suggested that chitosan and silica sand can be used for six life cycles (180 min) and after that it can be washed with water to remove salts and again be reused.

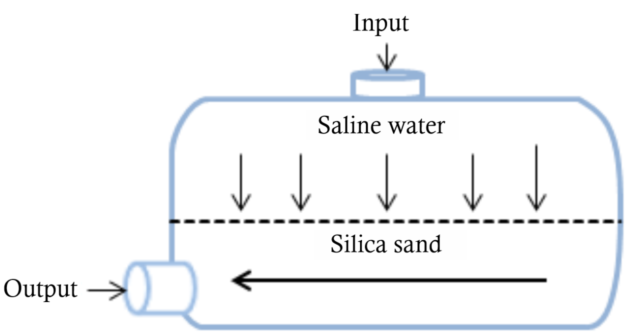

Fig. 6 Schematic diagram of filtration technique used for drip irrigation system

It can be concluded that by using a combination of batch and column method electrical conductivity (EC) of 5.0 dS m^{-1} can be reduced to 3.34 dS m^{-1} with a contact time of 30 minutes.

Table 8. Salt adsorption (EC) at different contact time using drip irrigation system

S. No.	Adsorbent	Contact time (minutes)	EC (initial) (dS m^{-1})	EC (final) (dS m^{-1})	Salt adsorption (Percent)
1	Silica sand	10	3.8	3.64	4.0
2	Silica sand	15	3.8	3.49	8.0
3	Silica sand	30	3.8	3.34	12.0
4	Silica sand	60	3.8	3.30	13.0

Conclusions

The adsorbent chitosan and silica sand were able to reduce electrical conductivity (EC) by approx. 24 and 12 percent respectively. Optimum contact time was found out to be 30 minutes for both the adsorbents. It can be concluded that by using a combination of chitosan and silica sand, electrical conductivity (EC) of 5.0 dS m^{-1} can be reduced to 3.34 dS m^{-1} with a contact time of 30 minutes. Adsorbent silica sand and chitosan can be reused for 6 life cycles (180 min). The same silica sand and chitosan material can be washed out to remove salts adsorbed on their surface by tap water and can be again reused to reduced electrical conductivity.

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