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Assessment Of Fluoride Removal By Membrane Capacitive Deionization

*Pragya Bohra[1],Mayank Vyas[1],Dr. Anil Vyas[2],Dr. Suresh Kumar Singh[3]
[1]Master Degree Scholar, Civil Engineering Department, M.B.M. Engineering College, Jodhpur (India)
[2]Associate Professor, Chemical Engineering Department, M.B.M. Engineering College, Jodhpur (India)
[3]Professor, Civil Engineering Department, M.B.M. Engineering College, Jodhpur (India)
*Corresponding Author: *Pragya Bohra*

ABSTRACT: *Water is the symbol of existence of life. In the modern industrial era, we have used water so careJlessly. To complicate matters, increasing groundwater extraction around the globe results in progressive salt water ingress in wells and aquifers. Potable water as well as water for agriculture and industry has become critical. Rajasthan is the largest state, which covers 10% of the country area but receives only 1/100 of the total rains. It shares only 1/10 of the average share of water than rest of the country. The geographical and geological setup leads to deterioration of water quality. Therefore, state faces acute water crisis making Groundwater a centralized source of drinking water for millions of rural and urban families in Rajasthan. Unfortunately, Groundwater is deeper and contains high minerals and concentrated chemicals, making the water unfit to drink. Water quality standards are not meeting the prescribed Indian standards. Underground water of twenty three districts of Rajasthan contain high fluoride, which causes adverse health effects i.e. Dental fluorosis, skeletal fluorosis, nonskeletal manifestation etc. Many reverse osmosis plants have been installed in Rajasthan for removal of fluoride from ground watJer. But, due to high power consumption, scaling and fouling of membranes, reduced water recovery and poor maintenance, most of the RO plants are not working properly. Thus, alternative technology is required with low power consumption and maintenance cost for the treatment of underground water. The study was carried out to evaluate efficiency of membrane capacitive deionization for removal of fluoride from underground water with elevated electric conductivity in the western Rajasthan. Accordingly, certain areas of Jodhpur and Jaisalmer districts were selected as the study area. The pilot plant (CapDI) manufactured by Voltea (Netherland) was provided by InNow India Pvt. Ltd for carrying out this study. It is found that MCDI technology is very effective in fluoride removal if total dissolved solids concentration is less than 5000 mg/ lt and percentage reduction of fluoride by MCDI technology is almost same as of by reverse osmosis technology. It was found that MCDI technology requires less power &gives more water recovery with low maintenance cost. Therefore it can be said MCDI technology is better than reverse osmosis technology.*

Keywords: *Fluoride, Membrane capacitive deionization (MCDI), Water Recovery, Reverse osmosis*

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I. INTRODUCTION

Inadequate rainfall and Inattentive use of Water has resulted in critical water scarcity. Rajasthan is the largest state, which covers 10% of the country area but receives only 1/100 of the total rains. It shares only 1/10 of the average share of water than rest of the country [1]. Groundwater is the principal source of drinking water in rural and urban Rajasthan. Due to careless use, continuous groundwater extraction, reduced rainfall and geographical setup, groundwater contains much elevated amount of salts making water unfit for not only drinking but also for other purposes. As far as Fluoride is concerned, Ground water fluoride contents in high levels are present in all 33 districts and have become a serious health related issue in 23 districts of Rajasthan [2]. Higher concentration of fluoride in water causes adverse health effects i.e. Dental fluorosis, skeletal fluorosis, nonskeletal manifestation etc. Many reverse osmosis (RO) plants have been installed in Rajasthan for removal of fluoride from ground water. But, due to high power consumption, scaling and fouling of membranes, reduced water recovery and low maintenance, most of the RO Plants are not working properly. Thus, alternative technology is required with low power consumption and maintenance cost for the treatment of underground water. Membrane capacitive deionization is the emerging technology which provides higher percentage of salt removal with lower power consumption. The energy efficiency of Membrane Capacitive Deionization M(CDI) is due to the fact that the salt ions, which are the minority compound in the water, are removed from the mixture. Instead, other methods extract the majority phase, the water, from the salt solution. Furthermore, energy release during electrode regeneration (ion release, or electrode discharge) can be utilized to charge a neighboring cell operating in the ion electrosorption step, and in this way energy recovery is possible [3]. CDI is a two stage process. In the purification step, A saltwater process stream flows between two electrodes held at a potential difference of around 1.2-1.5 V. Ions in the solution are attracted to the oppositely charged electrodes. The ions are electrosorbed onto the electrodes, removing them from the process stream, and the deionization cycle continues until the electrodes are saturated with ions. Then, during the regeneration cycle, the two electrodes are discharged or the polarity of the electrodes is reversed. This releases the ions into a waste stream, which has a much higher salt concentration than the process stream. One of the most promising recent developments in CDI is to include ion-exchange membranes (IEMs) in front of the electrodes, called Membrane Capacitive Deionization (MCDI). IEMs can be placed in front of both electrodes, or just in front of one. With only one IEM, the overall positive effect on salt adsorption is less pronounced than in the case of using two IEMs. IEMs have a high internal charge because of covalently bound groups, and therefore allow easy access for one type of ion (the counterion) and block access for the ion of equal charge sign (the co-ion) [3].

1.1 Working of MCDI:

Removal of fluoride by MCDI is done by applying constant current with varying voltage , so method is known as constant current(CC).

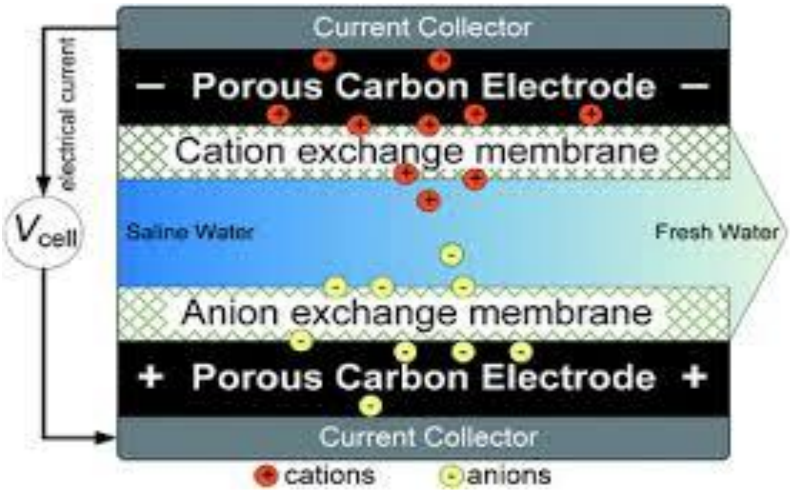

Fig 1.0 Membrane Capacitive Deionization.

In CC-operation the effluent salt concentration level remains at a fairly constant value, namely at a constant low value during adsorption, and at a constant high value during desorption. Another advantage of CC operation is that one can precisely tune the effluent salt concentration level by adjusting the electrical current, or water flow rate, as control parameters. CC operation works only in MCDI and not in CDI. Instead, in CDI-CC the effluent salinity changes throughout the adsorption step, indicating that the salt adsorption rate is not constant, even though in CC-mode operation.

This is due to the fact that in CDI the electrical current is partially compensated by counter ion adsorption and for the other part by co-ion desorption. The co-ion desorption effect decreases at high voltages and then the current is directly proportional to water desalination rate, but this is not yet the case at low cell voltages. Thus the salt adsorption rate by the full cell pair changes as function of time and this is why in CDI-CC the effluent salinity does not quickly level off to the desired constant. For CC operation in combination with membranes (MCDI-CC), Constant levels of the effluent salt concentration are quickly reached after start of a new adsorption step, because the co-ions are kept within the electrode structure and only counter ions carry the ionic current. The study was carried out keeping the current constant 240 ampere and voltage as a variable.

1.2 Study Area:

Jodhpur and Jaisalmer districts fall under the areas of western Rajasthan . Both Districts do not receive adequate amount of rainfall, making ground water primary source of drinking water in rural areas. According to a study carried out in 2014 by Center of Info for Biotechnology among the total population surveyed 37.3% female and 38.8% males were suffering from very mild form of dental fluorosis. 18% female and 17. 6% males have mild form of dental fluorosis. 7.2% female and 11.4% males from were having moderate form of dental fluorosis whereas 5.4% female and 6.5% males were having severe form of dental fluorosis [4]. The study was conducted on water samples from Raiko ki Basni, Charano ki Dhani, NPH Chowki, PWD colony Jodhpur and Ghantiyali, Kuria, Kishangarh (border areas) Jaisalmer district.

II. METHODOLOGY AND OBSERVATIONS

Membrane Capacitive Deionization Pilot Plant was established at PWD colony of Jodhpur where the source of water was tube well. Other water samples were collected from different areas of Jodhpur and Jaisalmer and transported in tankers. These samples were treated and reduction ion fluoride was assessed, other parameters such as Recovery of water, Current capacity (240 A) were kept fixed. Electric conductivity was taken as secondary parameter, as power consumption of the plant varies with variation in electric conductivity. The plant specifications were as given below. Treated water samples were collected and concentrations of fluoride were measured. Observations are given in table-1.

Plant Specifications:

- Model: System IS 6 (Have 6 units of M(CDI) module)
- Instant Flow Rate : 0.5 – 6.1 m^3/h
- Net Produced Flow: 2.4 – 3.5 m^3/h
- Salt Removal: 25-98% (Adjustable)
- Water Recovery: 40-90% (Adjustable)
- System Power Requirement Single - Phase (4 kW)
- Water Feed Pressure: ≥ 6.0 m^3/h , 3 bar
- Water Temperature 5 - 60 °C (40 - 140 °F)
- Number of cycles : 3 (Kept Constant)

In whole process current remains constant for a certain set percentage removal in both pure and waste cycle. When cycle changes from pure to waste, the current drops to zero and starts increasing to certain value. After reaching certain value it becomes constant for that cycle and voltage varies with increasing or decreasing percentage removal. By adjusting the desired set percentage removal in the plant will be reflected in the percentage change in electric conductivity. The removal of fluoride with respect to reduction in overall salt concentration was studied.

Table -1 Comparison of percentage reduction of electric conductivity, and percentage removal of fluoride

Source Place	Feed water Conductivity (µS/cm)	Feed water Fluoride (mg/l)	Parameters	Set and observed Percentage Removal in fluoride and Electric Conductivity (EC)			
				50%	75%	90%	98%
Kuria	2742	1.41	Fluoride	21.98	41.84	83.68	93.68
			EC	42.3	73.66	90.4	97.41
Ghantiyali	3852	2.24	Fluoride	15.17	64.28	75	78.125
			EC	47.55	73.13	90	95.79
Charano ki Dhani	8871	3.13	Fluoride	32.9	61.66	-	-
			EC	38.99	70	-	-
NPH Chowki	2461	3.32	Fluoride	27.71	48.79	75.30	82.53
			EC	51.23	75.1	91.7	97.8
Kishangarh	2422	3.76	Fluoride	44.14	74.73	85.37	88.56
			EC	47.15	69.03	90.8	97.44
Raiko Ki Basni	5012	4.14	Fluoride	27.53	44.44	49.27	-
			EC	45.88	67.5	76.217	-
PWD Colony	1842	7.8	Fluoride	57.69	67.94	87.179	91.02
			EC	48.37	70.1	91.8	98.2

From Table -1 it is apparent that Raiko ki basni water sample having Electric Conductivity 5000 µS/cm, there is very slight difference in percentage fluoride removal for different set percentage removal that is, 44.44% fluoride removal for 75% and 49.27% fluoride removal for 90% set percentage removal. Similar was observed for water sample from Charano ki dhani with Electric conductivity 8872 µS/cm on 75% set removal. This is because for higher electric conductivity, machine does not work efficiently. As it reaches its maximum current capacity 240A.

2.3 Power Consumption Details :-

Power Consumed by MCDI plant during treatment depends on number of cycles run, set percentage removal, feed water quality etc. In this study number of cycles was kept same for each set percentage removal. The detailed power consumption for different feed electric conductivity of different sources is described in Table 2.

Table -2: Power consumed in Fluoride removal.

Source	Feed water Conductivity (mg/l)	Power consumption for preset parentage reduction (KWH)			
		50%	75%	90%	98%
PWD Colony	1842	0.17	0.35	0.54	0.78
NPH Chowki	2461	0.19	0.36	0.62	0.81
Kuria	2742	0.19	0.36	0.62	0.84
Kishangarh	2422	0.19	0.42	0.81	0.86
Ghantiyali	3852	0.26	0.76	0.89	0.98
Raiko Ki Basni	5012	0.26	0.89	0.98	-
Charano Ki Dhani	8872	0.86	1.06	-	-

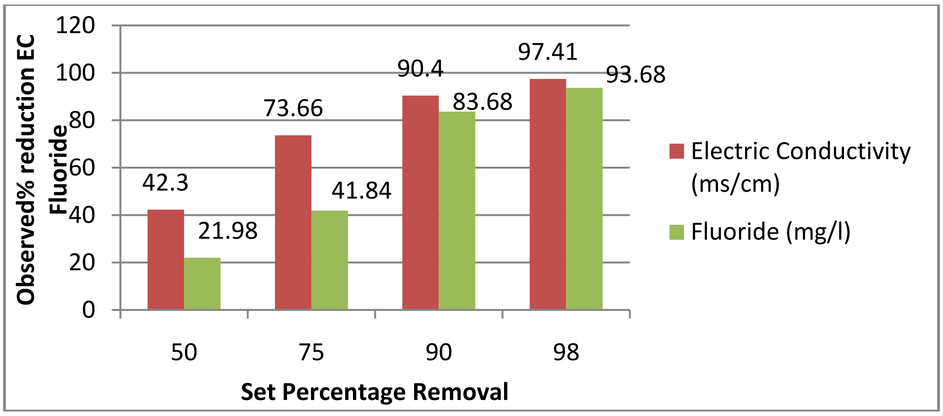

Figure -2: Comparison of Fluoride Removal and reduced EC By MCDI of Kuria water sample.

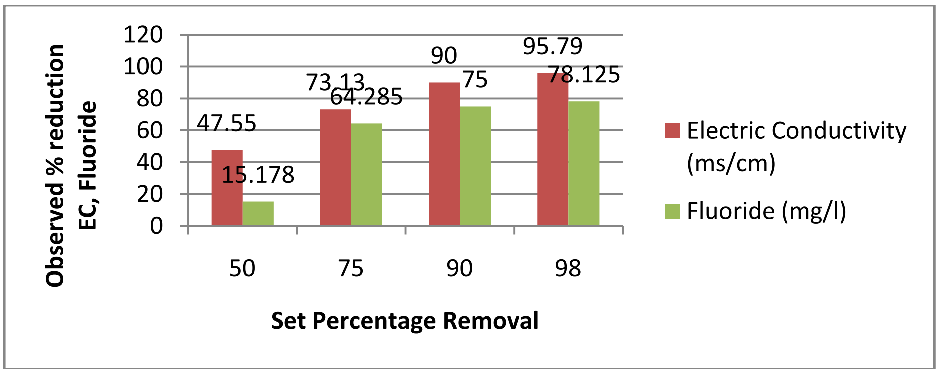

Figure -3: Comparison of Fluoride Removal and reduced EC By MCDI of Ghantiyali water sample.

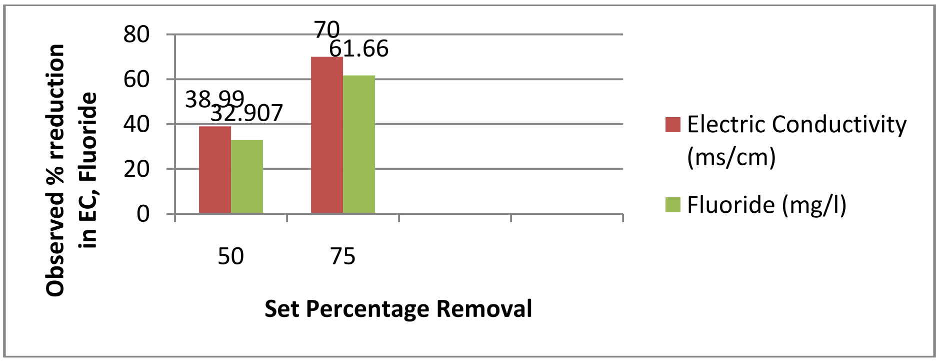

Figure -4: Comparison of Fluoride Removal and reduced EC By MCDI of Charano ki Dhani water sample.

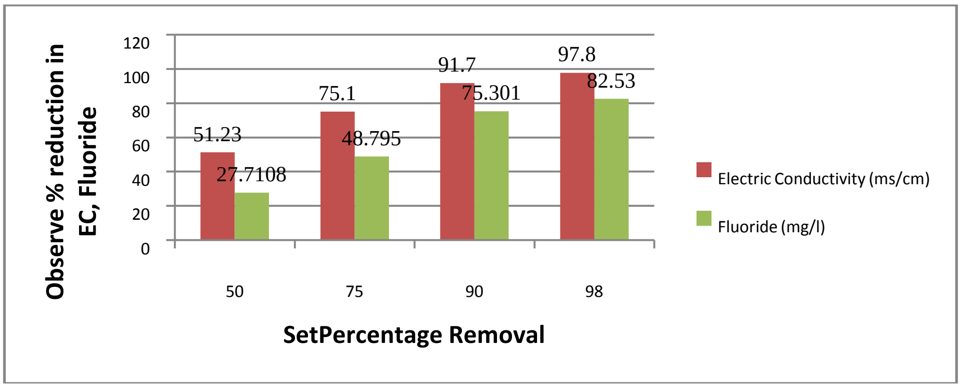

Figure -5: Comparison of Fluoride Removal and reduced EC By MCDI of NPH Chowki water sample.

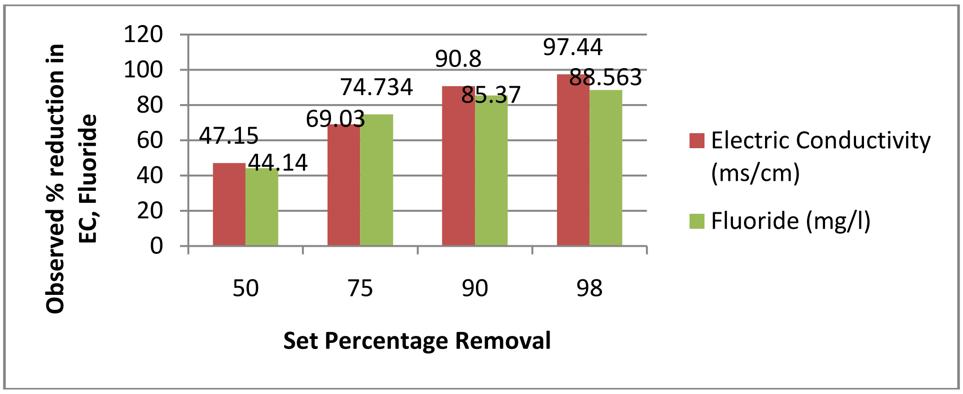

Figure -6: Comparison of Fluoride Removal and reduced EC By MCDI of Kishangarh water sample.

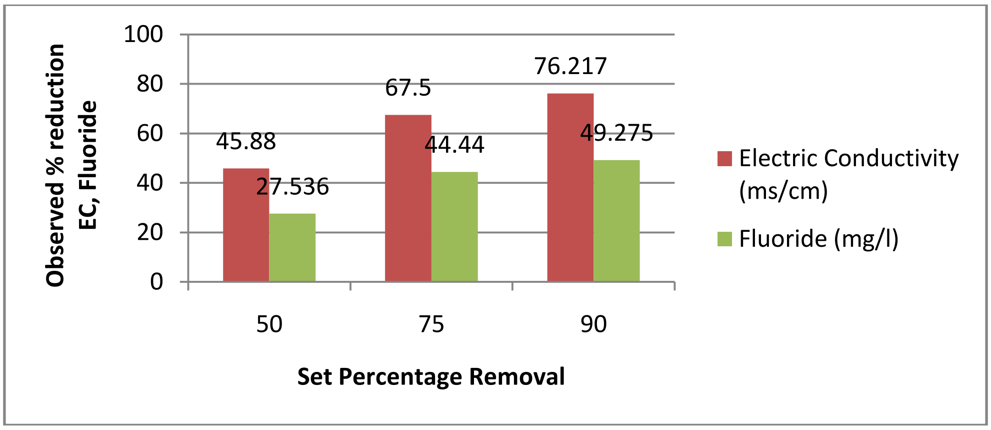

Figure -7: Comparison of Fluoride Removal and reduced EC By MCDI of Raiko ki Basni water sample.

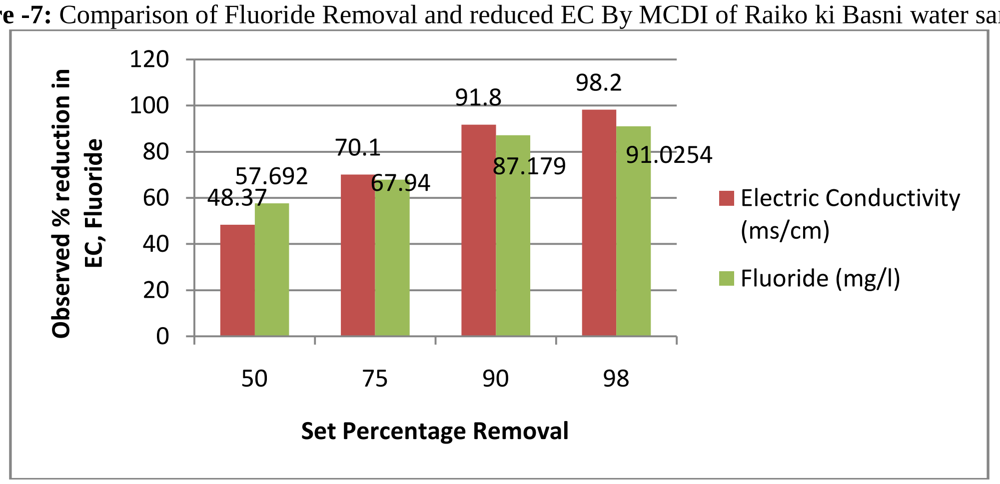

Figure -8: Comparison of Fluoride Removal and reduced EC By MCDI of PWD Colony water sample.

It is evident from the power consumption details that with increase in conductivity, power consumption increases. For Charano ki dhani water sample with maximum conductivity 8872µS/cm, power consumption was also found to be maximum 1.06KWH. Also, during the treatment operation the plant reached to its maximum current capacity 240A for charano ki dhani and Raiko ki basni water sample with second highest electric conductivity.

III. CONCLUSION

Fluoride removal analysis from membrane assisted capacitive deionization plant was carried out on groundwater of Jodhpur and Jaisalmer district of Rajasthan (India) . The Major aim of the study was to analyze the capacity of the plant to remove fluoride and the power consumed in the removal of fluoride. Electric Conductivity was taken as secondary parameter, as power consumption of the plant varies with variation in Electric conductivity. Membrane assisted capacitive deionization facilitates adjustment of desirable percentage removal. It was observed that the plant performed the best until the conductivity of the water was below or around 5000µS/cm. With the increase in conductivity of water above 5000µS/cm, the plant could not perform efficiently. This happened because the plant reached its maximum current. For example, sample from Ghantiyali had the conductivity of 1894µS/cm, and sample from charano ki dhani had the conductivity of 8872µS/cm. percentage reduction of up to 98% in electric conductivity was observed in Ghantiyali water sample but it could remove the conductivity by 75% in water sample from charano ki dhani and the conductivity was reduced to 2661 µS/cm, as current reached to its limit of 240 A. Comparison between fluoride removal and Electric conductivity was also considered. Water sample from PWD colony Jodhpur was found having maximum fluoride concentration of 7.8 mg/l. With MCDI it was possible to bring the fluoride level to 0.7mg/l with 98% set percentage removal. However, MCDI facilitates 68 to 70% recovery without scaling issues. Though, higher conductivity hinders the removal of fluoride, but increase in current capacity can lead to increased fluoride removal. Lower scaling issues, less power consumption proves membrane assisted capacitive deionization technology to be more effective and energy efficient than reverse osmosis to remove fluoride if EC is less than 5000µS/cm.

REFERENCES

[1]. Hussain, J. , Sharma, K. C. ,Hussain, I, "Fluoride in drinking water in rajasthan and its ill effects on human health", Journal of Tissue Research Vol. 4 (2) 263-273 (2004)

[2]. Rajini Agarwal, A Brief Review on Fluoride Concentration in Drinking Water in Malpura Tehsil (Tonk, Rajasthan, India), Bassi Tehsil (Jaipur, Rajasthan, India) and Vicinity Areas of Dausa District (Rajasthan, India), International Journal of Green and Herbal Chemistry, September 2014 – November -2014; Sec. A; Vol.3, No.4, 1507-1512

[3]. S. Porada, R. Zhao, A. van der Wal, V. Presser, P.M. Biesheuvel, Review on the science and technology of water desalination by capacitive deionization, Progress in Materials Science 58 (2013) 1388 - 1442

[4]. Vibha Joshi and Nitin Kumar Joshi," Fluorosis and its impact on public health in jodhpur, Rajasthan" International Journal of Basic and Applied Medical Sciences 2014 Vol. 4 (2)

[5]. Zhao R, Biesheuvel PM, Van der Wal A. Energy consumption and constant current operation in membrane capacitive deionization. Energy Environ Sci 2012;5:9520–7.

[6]. Li H, Gao Y, Pan L, Zhang Y, Chen Y, Sun Z. Electrosorptive desalination by carbon nanotubes and nanofibres electrodes and ion-exchange membranes. Water Res 2008;42:4923–8.

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