# COMPARATIVE STUDY OF MEMBRANE CAPACITIVE DEIONIZATION TECHNOLOGY AND REVERSE OSMOSIS FOR FLUORIDE REMOVAL FROM WATER

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***Abstract*—Two thirds of the world's populations currently live in areas that experience water scarcity for at least one month a year. The whole world is concerned for the availability of clean and potable water. Most of the available water is saline and is not potable. Water supplies are running out of the actual water needs of the society. Therefore, Rajasthan faces acute water crisis. The great Indian Thar Desert covers where extremely arid and dry climate conditions prevail, receiving 5 mm to 20 mm annual rainfall, making Ground water centralized source of drinking water. Groundwater is deeper and contains high mineral concentrated chemicals which makes the water unfit to drink. Unfortunately, the groundwater quality in a large number of districts is not according prescribed standards. Rajasthan is the only state where all most all the districts are affected by high fluoride (beyond the permissible limit). In 23 districts the fluorosis problem can be visualized at various intensity level i.e. Dental fluorosis, skeletal fluorosis, nonskeletal manifestation etc.Various Technologies have been developed so far for deflouridation. Many Reverse osmosis plants have been installed in Rajasthan for removal of fluoride from ground water. But, it is associated with high power consumption, scaling and fouling of membranes and reduced water recovery. This sets up a need for more energy efficient device with less maintenance and operational cost with overcoming shortcomings of reverse osmosis. Membrane capacitive deionization is the emerging technology which utilizes constant current method with varying voltage to remove salts from underground water. The pilot plant (CapDI) manufactured by Voltea (Netherland) was provided by InNow India Pvt. Ltd for carrying out this study. It was found that Capacitive deionization technique is very efficient in removal of low salinity feed water sources. Energy consumption is quite low approximately only 20 to 30% of energy utilized by reverse osmosis. And flow recovery rate of CapDI plant is also high than reverse osmosis plant.***

***Index Terms*— Fluoride, Membrane capacitive deionization, Reverse Osmosis**

## I. INTRODUCTION

Fluorosis is an important public health problem in 24 countries, including India, which lies in the geographical fluoride belt that extends from Turkey to China and Japan through Iraq, Iran and Afghanistan.[11] Of the 85 million tons of fluoride deposits on the earth's crust, 12 million are found in India.[10] Hence it is natural that fluoride contamination is widespread, intensive and alarming in India. The available data suggest that 15 States in India are suffering from fluorosis (fluoride level in drinking water >1.5 mg/l), and about bout 62 million people in India suffer from dental, skeletal and non-skeletal fluorosis. Out of these; 6 million are children below the age of 14 years.[12]The main source of fluoride in groundwater is the rocks which are rich in fluoride. 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]The geographical and geological setup leads to deterioration of water quality. Therefore, state faces acute water crisis. The great Indian Thar Desert covers where extremely arid and dry climate conditions prevail, receiving 5 mm to 20 mm annual rainfall. Groundwater is deeper and contains high mineral concentrated chemicals which makes the water unfit to drink. The eastern part of the state is semi desert and hilly, therefore the water availability in this region is also limited. Due to arid and semi arid climate and insufficient surface water resources, Rajasthan is indebt heavily on ground water for drinking and for agriculture purpose. Unfortunately, the groundwater quality in a large number of districts is not according prescribed standards. Rajasthan is the only state where all most all the districts are affected by high fluoride(beyond the permissible limit). In 23 districts the fluorosis problem can be visualized at various intensity level i.e. Dental fluorosis, skeletal fluorosis, nonskeletal manifestation etc. the study made by Rajasthan Voluntary Health Association in 1994 have showed that the total number of villages having fluoride problem in rajasthan is 2433 covering nearly 2.6 million population. Moreover, nearly 30,000 people are drinking water with concentration of 10.0 mg/l.

By definition, Membrane Capacitive Deionization is a combination of conventional Capacitive Deionization with ion-exchange membranes (IEMs) placed in front of the electrodes. Ion exchange membranes can be positioned in front of one or both electrodes. Ion-exchange membranes have a high internal charge due to covalently bound groups such as sulfonate or quaternary amines, which allows easy access for one type of ion (the counter ion) and block access for the ion of equal charge sign (the co-ion). Addition of Ion-exchange membranes significantly improves desalination performance of the Capacitive Deionization process, in terms of salt adsorption, charge efficiency and energy consumption. The membranes can be included as stand-alone films of thicknesses between 50 and 200 μm, or can be coated directly on the electrode with a typical coating thickness of 20 μm[2].

### *MCDI Working*

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

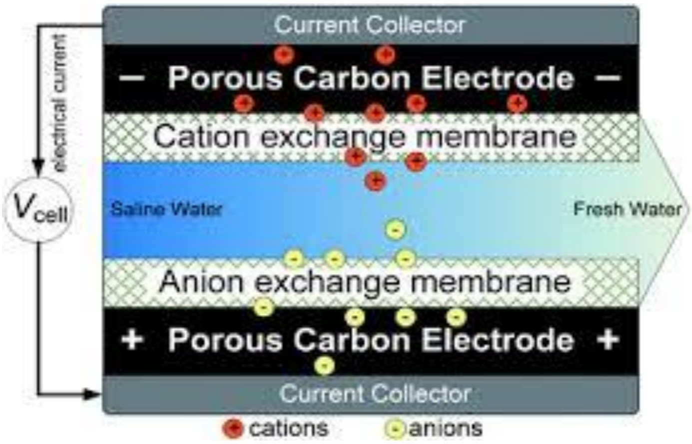


**Figure 1 membrane capacitive deionization.**

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 counterion 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[3]. The study is carried out keeping the current constant 240 ampere and voltage as a variable.

***Study Area***

Some places (RaikokiBasni, CharanokiDhani, NPH Chowki, PWD colony Jodhpur and Ghantiyali, Kuria, Kishangarh) of Jodhpur and Jaisalmer districts were taken as study places as in these districts underground water have higher Fluoride concentrations. Where, PWD Colony situated in Jodhpur, have maximum fluoride concentration.

## II. Methodology and Observations

The Pilot Plant (CapDI) was established at PWD colony of Jodhpur where tube well was the source of water. Other water samples were collected and transported in tankers from different selected underground sources. By keeping Water recovery, Current capacity (240 A), Number of cycles (3) as constants, all these samples were treated and reduction in TDS was assessed. 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.

Plant Specifications:

- Model: System IS 6 (Have 6 units of M(CDI) module)
- Instant Flow Rate: 0.5 – 6.1 m3/h
- Net Produced Flow: 2.4 – 3.5 m3/h
- Salt Removal: 25-98% (Adjustable)
- Water Recovery: 40-90% (Adjustable)
- System Power Requirement Single - Phase (4 kW)
- Water Feed Pressure: ≥ 6.0 m3/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 salts from MCDI with respect to reduction in salt concentration from RO was studied.

## III. Comparative Data of MCDI and RO

**Table 1 Comparative data of fluoride removal by CapDI and RO of similar feed concentration from Kuria and Jakhan.**

| Treatment process | Source | Plant Capacity (LPH) | Fluoride in feed water (mg/l) | Fluoride in treated water (mg/l) | Fluoride removal efficiency | Power Consumed |
|---|---|---|---|---|---|---|
| CapDI | Kuria | 1000 | 1.41 | 0.089 | 93.68 | 0.84 |
| RO | Jakhan | 1000 | 1.4 | 0.1 | 92.8 | 4 |

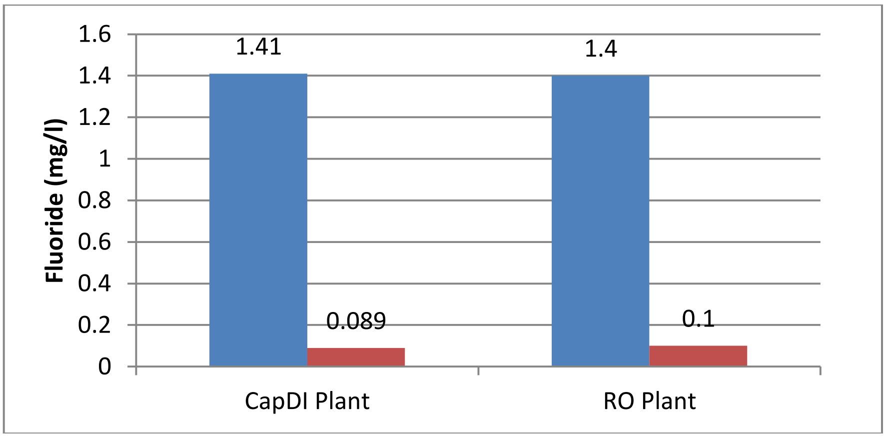


**Figure 2 Reduction in fluoride by CapDI and RO of similar feed concentration from Kuria and Jakhan**

**Table 2 Comparative data of fluoride removal by CapDI and RO of similar feed concentration from Charano ki Dhani and Khara.**

| Treatment process | Source | Plant Capacity (LPH) | Fluoride in feed water (mg/l) | Fluoride in treated water (mg/l) | Fluoride removal efficiency | Power Consumed |
|---|---|---|---|---|---|---|
| CapDI | Charano ki Dhani | 1000 | 3.13 | 1.2 | 61.66 | 1.06 |
| RO | Khara | 1000 | 3.1 | 0.1 | 96.77 | 4 |

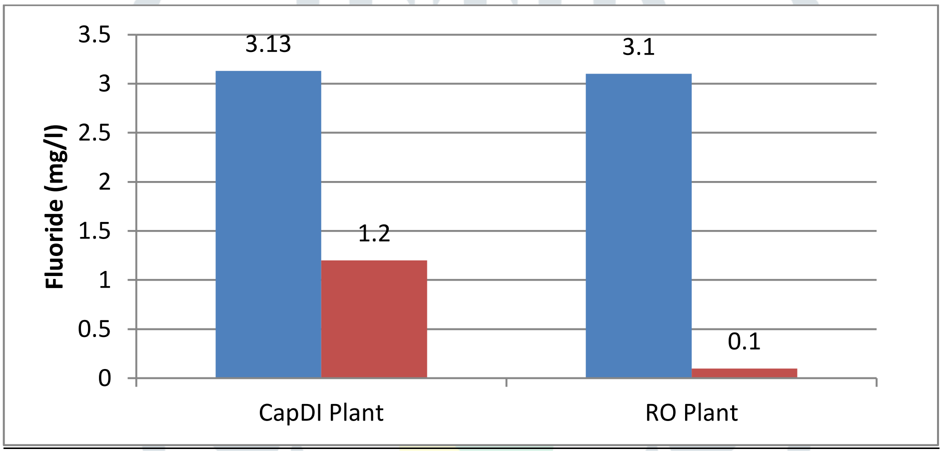


**Figure 3 Reduction in fluoride by CapDI and RO of similar feed concentration from Charano ki Dhani and Khara**

Sample from charano ki dhani was with maximum Electric Conductivity 8871 µS/cm, machine reached its maximum current capacity 240A on 75% set percentage removal. Whereas, data collected from Khara where Reverse osmosis technology is used, 96% fluoride removal took place with 13, 164 µS/cm Electric Conductivity

**Table 3 Comparative data of fluoride removal by CapDI and RO of similar feed concentration from NPH Chowki and Raneri.**

| Treatment process | Source | Plant Capacity (LPH) | Fluoride in feed water (mg/l) | Fluoride in treated water (mg/l) | Fluoride removal efficiency | Power Consumed |
|---|---|---|---|---|---|---|
| NPH Chowki | 1000 | CapDI | 3.32 | 0.58 | 82.53 | 0.81 |
| Raneri | 1000 | RO | 3.3 | 0.1 | 96.96 | 4 |

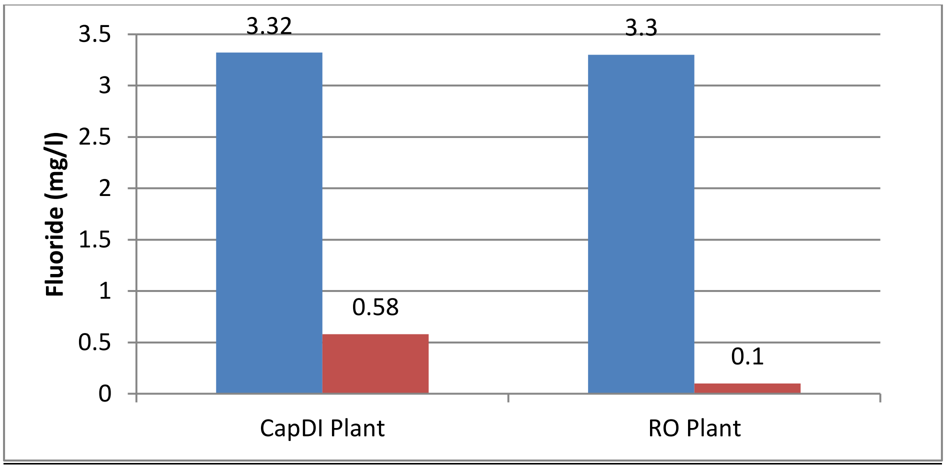


**Figure 4 Reduction in fluoride by CapDI and RO of similar feed concentration from NPH Chowki and Raneri**

**Table 4 Comparative data of fluoride removal by CapDI and RO of similar feed concentration from Raiko ki Basni and Dayakor**

| Treatment process | Source | Plant Capacity (LPH) | Fluoride in feed water (mg/l) | Fluoride in treated water (mg/l) | Fluoride removal efficiency | Power Consumed |
|---|---|---|---|---|---|---|
| Raiko ki Basni | CapDI | 1000 | 4.14 | 2.1 | 49.27 | 1.03 |
| Dayakor | RO | 1000 | 4.6 | 0.2 | 95.65 | 4 |

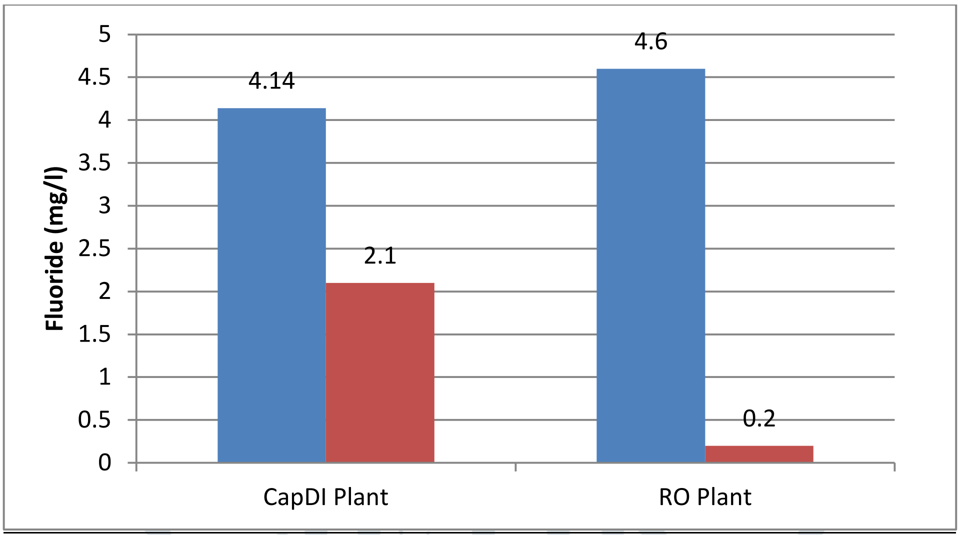


**Figure 5 Reduction in fluoride by CapDI and RO of similar feed concentration from Raiko ki Basni and Dayakor.**

## IV. Conclusions

Study was carried out on the raw water sample collected from the various location situated in Jodhpur and Jaisalmer district out of which three locations Ghantiyali, Kuria, and Kishangarh are situated at border area of Jaisalmer. And other locations of Jodhpur district are Raiko ki Basni, Charano ki Dhani, NPH Chowki, PWD colony. The water was directly feed to the capacitive deionization plant and treated for various preset percentage removal efficiency of salt and analyzed for Fluoride removal, power consumption and percentage flow recovery.

For a comparative study with RO plant, data of various location having similar Fluoride Concentration in raw water collected from web site of Public health engineering department, Rajasthan. It was found that Capacitive deionization technique is very efficient in removal of low salinity feed water sources (EC< 3,000 mg/L). Energy consumption is quite low, approximately only 20 to 30%of energy utilized by RO Plant. CapDI plant have small footprint almost half the size of RO plant. There is no issue of fouling in CapDI plant which is usually seen in RO plant, fouling of hydrophobic membrane when the membrane is wetted. However, (M) CDI 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. And increased recovery, lower scaling issues, less power consumption proves Membrane assisted capacitive deionization, to be more energy efficient than reverse osmosis.

## 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] Anderson, M. A., Cudero, A. L., & Palma, J. (2010). Capacitive deionization as an electrochemical means of saving energy and delivering clean water. Comparison to present desalination practices: Will it compete? Electrochimica Acta, 55(12), 3845-3856.

[5] Arras, W., N. Ghaffour, and A. Hamou. Performance evaluation of BWRO desalination plant- A case study. Desalination, 235, 170 (2009).

[6] Biesheuvel, P.M. Thermodynamic cycle analysis for capacitive deionization. Journal of Colloid and Interface Science, 332, 258 (2009).

[7] Biesheuvel, P.M., Y. Fu, and M.Z. Bazant. Diffuse charge and Faradaic reactions in porous electrodes. Physical Review E, 83, 061507 (2011).

[8] Cath, T.Y., A.E. Childress, and M. Elimelech. Forward osmosis: Principles, applications, and recent developments. Journal of Membrane Science, 281, 70 (2006)