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EFFECTIVENESS STUDY OF MEMBRANE CAPACITIVE DEIONIZATION TECHNOLOGY IN TRACE METAL REMOVAL FROM WATER

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Abstract:
Increasing environment protection awareness made the availability of clean water, technological, social and economical challenge of the 21st century. Water, is a scarce amenity not only in India but in the whole world. Most of the available water is saline and is not potable. Water supplies are not matching the actual water needs of the society. We have been squandering and polluting water resources since ages and are now in need of finding cost competitive newer technologies for reclaiming this valuable life-sustaining liquid. Membrane capacitive deionization is one of those prominent technologies which assure to be more efficient with higher water recovery and less power consumption.
In this study concentration of trace metals viz. Barium, Arsenic, Lead, Chromium, Cadmium, Nickel and Boron in ground water samples from western Rajasthan were determined using Inductive coupled plasma- Optical emission Spectrometer (ICP-OES). These metals have toxic effects on the human health; most of them are carcinogenic and can cause fatal effects if consumed in fewer amounts continuously for long duration. This study has also been done to assess the removal of trace metals by membrane capacitive deionization process. Electrical conductivity of water was assessed to compare the results with trace metals. Certain areas of Jodhpur and Jaisalmer districts of Rajasthan state in India 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. The maximum EC was reduced by 98 %, whereas the trace metals Barium, Cadmium, Chromium and Boron were removed by 57%, 70%, 50%, and 74% respectively. Thus it can be interpreted from the study that Membrane Capacitive Deionization Technology can remove the Heavy and Toxic metals up to a certain limit effectively with low power consumption.

Keywords: *Chromium, Electric conductivity, Lead, Membrane capacitive deionization, Trace Metals, Water Recovery.*

I. INTRODUCTION

Potable Water is a scarce source. . Rajasthan is the largest state of India, Rajasthan shares only 1/10 of the average share of water than rest of the country [1]. Water supplies in most of the Indian cities including cities of Rajasthan are not matching the actual water need of the society. Groundwater is the major source of drinking water in some part of the Rajasthan. Presence of higher amount of salts and trace metals in underground water sources in the western Rajasthan is enhancing the less availability of potable water to the population. Trace metals removal from water in field is difficult. These are carcinogenic and can cause fatal effects if consumed in less amount for long duration. This study was done to evaluate removal of trace metals from membrane capacitive deionization.
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].

A. WORKING OF MCDI:

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

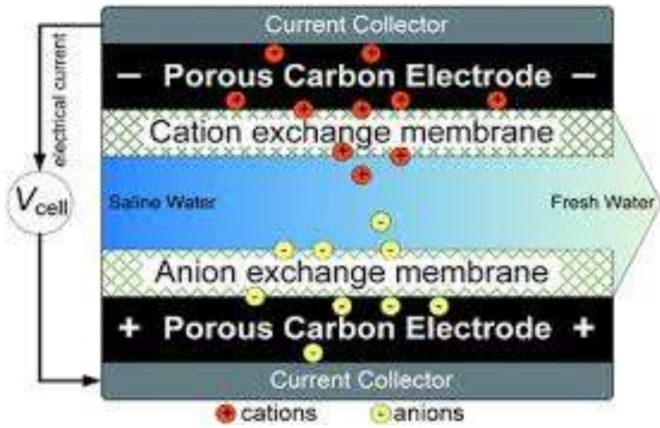

Figure 1 membrane capacitive deionization.

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.

B. STUDY AREA:

Some places (Raiko ki Basni, Charano ki Dhani, 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 high salt Concentrations. Both Districts do not receive adequate amount of rainfall, making ground water primary source of drinking water.

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 trace metals 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 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 trace metals with respect to reduction in overall salt concentration was studied.

Sample 1 – Ghantiyali

Table -1 Comparison of percentage reduction of electric conductivity, and percentage removal of Trace metals.

Parameter	Required Limit* (mg/lt)	Permissible Limit* (mg/lt)	Concentration in Feed water	Observed Percentage reduction in parameters for set percentage reduction in plant			
				50	75	90	98
EC (µs/ cm)	Not Defined	Not Defined	3882	48	73	90	96
Barium (mg/l)	0.7	No Relaxation	0.16	38	50	50	56
Boron (mg/l)	0.5	1	1.2	25	58	67	67
Chromium (mg/l)	0.05	No Relaxation	0.03	0	0	33	33
*Limits are as per Indian Standard Code IS : 10500							

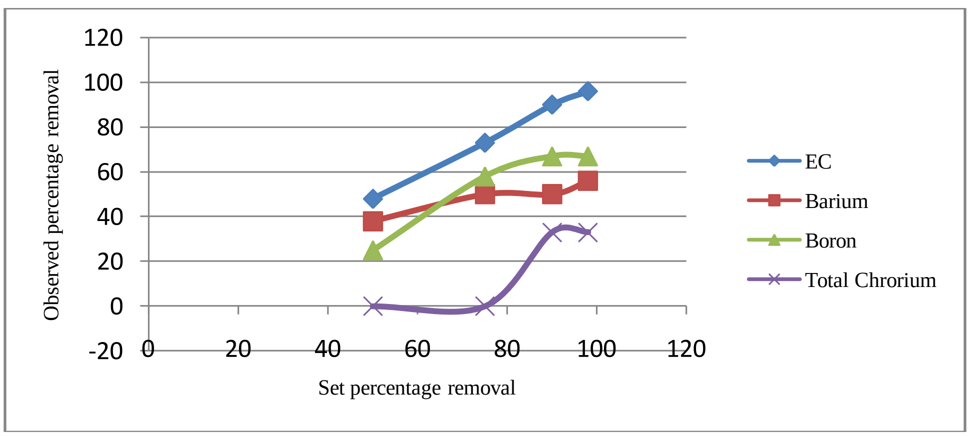

Figure -2: Comparison of Trace Metals Removal and reduced EC By MCDI of Ghantiyali water sample.

Sample 2 – Kuria PDF

Table -2 Comparison of percentage reduction of electric conductivity, and percentage removal of Trace metals.

Parameters	Required Limit* (mg/lt)	Permissible Limit* (mg/lt)	Concentration in Feed water	Observed Percentage reduction in parameters for set percentage reduction in plant			
				50	75	90	98
EC (µs/ cm)	Not Defined	Not Defined	2752	43	74	90	97
Barium (mg/l)	0.7	No Relaxation	0.07	14	43	57	57
Boron (mg/l)	0.5	1	1.61	29	46	60	73
Cadmium (mg/l)	0.003	No Relaxation	0.02	20	45	55	70
*Limits are as per Indian Standard Code IS : 10500							

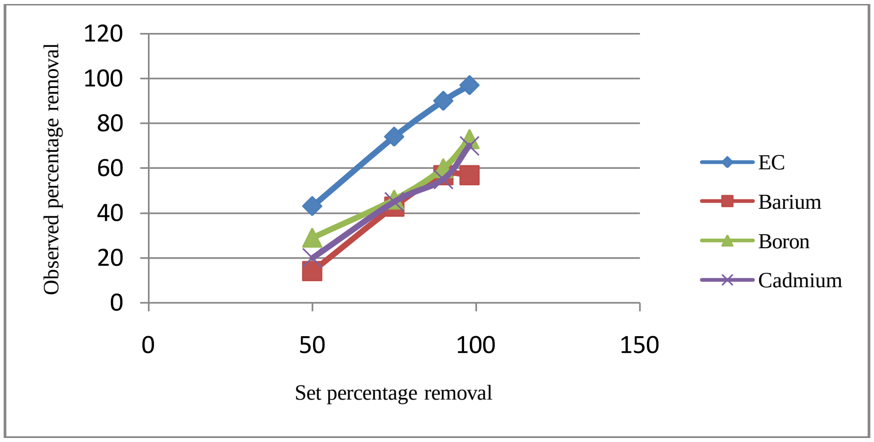

Figure -3: Comparison of Trace Metals Removal and reduced EC By MCDI of Kuria water sample.

Sample 3 – Kishangarh

Table -3 Comparison of percentage reduction of electric conductivity, and percentage removal of Trace metals.

Parameter	Required Limit* (mg/lt)	Permissible Limit*(mg/lt)	Concentration in Feed water	Observed Percentage reduction in parameters for set percentage reduction in plant			
				50	75	90	98
EC (μs/ cm)	Not Defined	Not Defined	2451	48	69	91	97
Barium (mg/l)	0.7	No Relaxation	0.08	25	38	38	50
Cadmium (mg/l)	0.003	No Relaxation	0.03	20	33	53	70
Nickel, (mg/l)	0.02	No Relaxation	0.03	0	33	33	67
Total arsenic, (mg/l)	0.01	0.05	0.06	0	33	33	67
*Limits are as per Indian Standard Code IS : 10500							

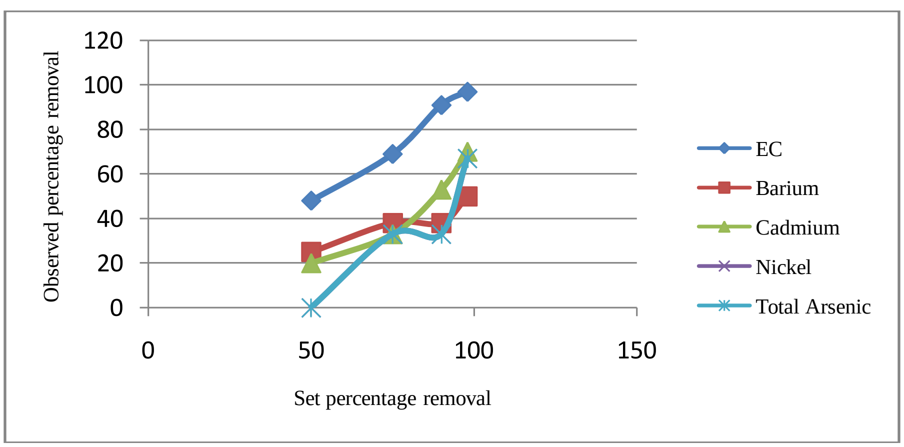

Figure -4: Comparison of Trace Metals Removal and reduced EC By MCDI of Kishangarh water sample.

Sample 4 – Raiko ki Basni

Table -4 Comparison of percentage reduction of electric conductivity, and percentage removal of Trace metals.

Parameter	Required Limit*(mg/lt)	Permissible Limit*(mg/lt)	Concentration in Feed water	Observed Percentage reduction in parameters for set percentage reduction in plant			
				50	75	90	98
EC (μs/ cm)	Not Defined	Not Defined	5001	46	68	76	76
Barium (mg/l)	0.7	No Relaxation	0.08	13	13	38	38
Cadmium (mg/l)	0.003	No Relaxation	0.02	25	40	60	60
Nickel (mg/l)	0.02	No Relaxation	0.02	0	50	50	50
*Limits are as per Indian Standard Code IS : 10500							

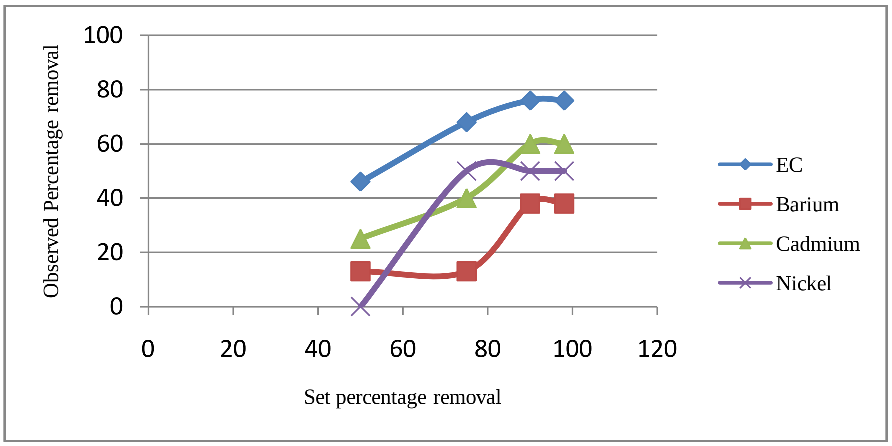

Figure -5: Comparison of Trace Metals Removal and reduced EC By MCDI of Raiko ki Basni water sample.

Sample 5 – Charano ki Dhani

Table -5 Comparison of percentage reduction of electric conductivity, and percentage removal of Trace metals.

Parameter	Required Limit* (mg/lt)	Permissible Limit*(mg/lt)	Concentration in Feed water	Observed Percentage reduction in parameters for set percentage reduction in plant			
				50	75	90	98
EC (μs/ cm)	Not Defined	Not Defined	8871	39	57	57	57
Boron (mg/l)	0.5	1	3.04	13	35	35	35
Cadmium (mg/l)	0.003	No Relaxation	0.02	15	45	45	45
Nickel (mg/l)	0.02	No Relaxation	0.07	14	43	43	43
Total Chromium (mg/l)	0.05	No Relaxation	0.14	21	50	50	50
*Limits are as per Indian Standard Code IS : 10500							

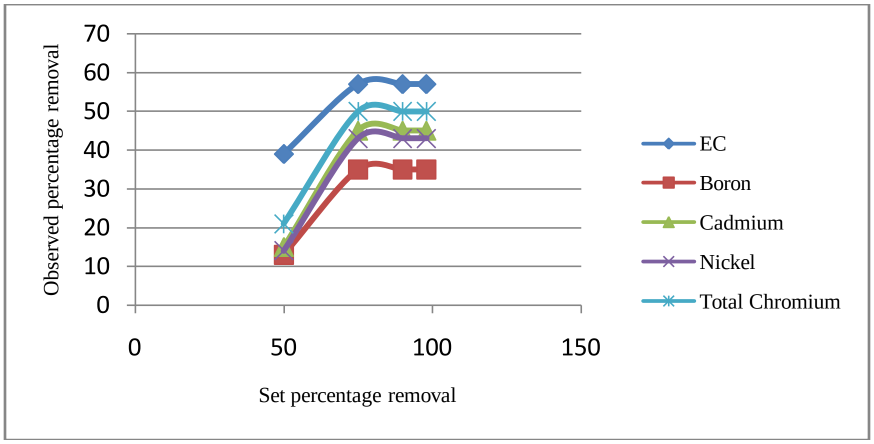

Figure -6: Comparison of Trace Metals Removal and reduced EC By MCDI of Charano ki Dhani water sample.

Sample 6 – NPH Chowki

Table -6 Comparison of percentage reduction of electric conductivity, and percentage removal of Trace metals.

Parameters	Required Limit* (mg/lt)	Permissible Limit* (mg/lt)	Concentration in Feed water	Observed Percentage reduction in parameters for set percentage reduction in plant			
				50	75	90	98
EC (µs/ cm)	Not Defined	Not Defined	2461	51	75	92	98
Boron (mg/l)	0.5	1	1.61	23	42	58	74
Cadmium (mg/l)	0.003	No Relaxation	0.02	15	45	55	65
Total Chromium (mg/l)	0.05	No Relaxation	0.04	0	25	25	25
*Limits are as per Indian Standard Code IS : 10500							

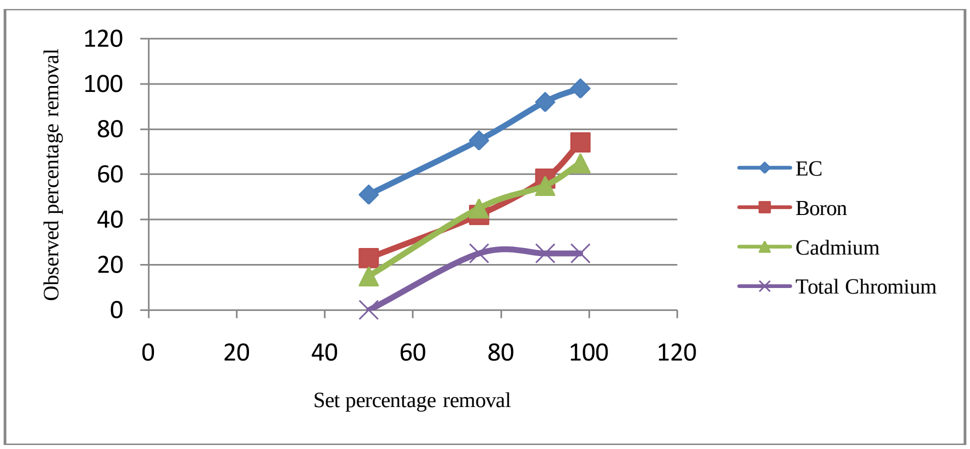

Figure -7: Comparison of Trace Metals Removal and reduced EC By MCDI of NPH Chowki water sample.

Sample 7 – PWD Colony

Table -7 Comparison of percentage reduction of electric conductivity, and percentage removal of Trace metals.

Parameter	Required Limit* (mg/lt)	Permissible Limit* (mg/lt)	Concentration in Feed water	Observed Percentage reduction in parameters for set percentage reduction in plant			
				50	75	90	98
EC (µs/ cm)	Not Defined	Not Defined	1862	49	70	92	98
Barium (mg/l)	0.7	No Relaxation	0.06	0	17	17	33
Boron (mg/l)	0.5	1	2.64	21	34	52	71
Cadmium (mg/l)	0.003	No Relaxation	0.02	25	35	50	60
Total Chromium (mg/l)	0.05	No Relaxation	0.02	0	0	50	50
*Limits are as per Indian Standard Code IS : 10500							

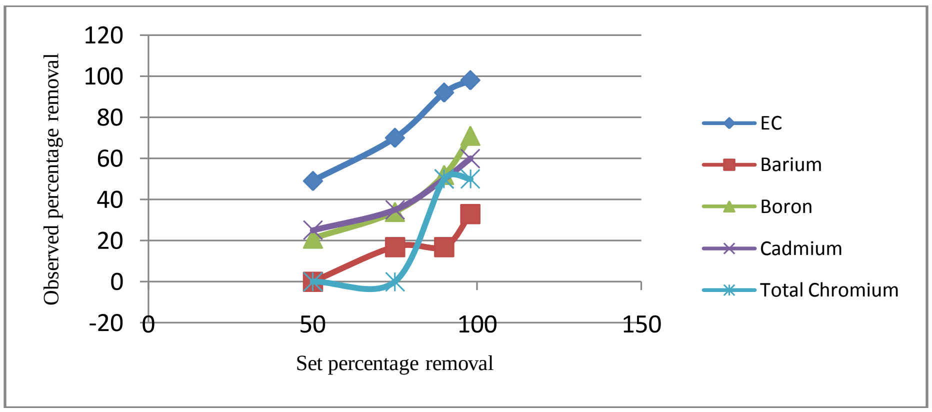

Figure -8: Comparison of Trace Metals Removal and reduced EC By MCDI of PWD Colony water sample.

It is observed that trace metals concentrations are reduced but with a lesser rate than electrical conductivity. If the conductivity of water is more than 5000 µs/ cm is than the results obtained for set percentage removal of 75, 90 & 98 approximately same as in these cases maximum designed current (i.e 240 A) reaches just after 50 % set percentage removal. It can be said that in machine, setting of 90 % or 98% removal carries no meaning.

III CONCLUSION

Study was carried out on the raw water sample collected from the various location situated in Jodhpur, and Jaisalmer district of Rajasthan in India. The water was directly feed to the capacitive deionization plant and treated for various preset percentage removal efficiency of trace metal and analyzed for trace metal reduction in treated water. Concentrations of trace metals like Ba, B, Cd, Pb, Ni, As, Cr etc. was determined using Inductive Coupled Plasma- Optical Emission Spectrometer (ICP-OES).Result shows that concentration of Boron was found, 3.04 mg/l (in sample no-5) which was maximum among all the feed water samples, which is greater than 0.5 mg/l (permissible limit) and Concentration of Nickel was found maximum at feed water sample no.5 and concentration was 0.07 mg/l which is greater than the permissible limit 0.02 mg/l. Concentration of Cadmium was found maximum at feed water sample no. 3 & value was 0.03 mg/l which is greater than the permissible limit 0.003 mg/l. Maximum concentration of Chromium was found 0.14 mg/l in feed water sample no. 5 and which was greater than the permissible limit 0.05 mg/l. CapDI Plant reduces the concentration of metals up to a considerably low level .The maximum EC was reduced by 98 %, whereas the trace metals Barium, Cadmium, Chromium and Boron were removed by 57%, 70%, 50%, and 74% respectively. Thus it can be interpreted from the study that Membrane Capacitive Deionization Technology can remove the trace and Toxic metals up to a certain limit effectively with low power consumption.

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