ASSESSMENT OF NITRATE REMOVAL BY MEMBRANE CAPACITIVE DEIONIZATION

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Abstract*—With the expanding condition, the accessibility of clean water has turned out to be key innovative, social and conservative difficulties of the 21st century. Around 1.2 billion individuals, or just about one-fifth of the total populace, live in ranges of physical shortage, and 500 million individuals are moving toward this situation.1 Another 1.6 billion individuals, or very nearly one fourth of the total populace, confront financial water deficiency (where nations do not have the vital foundation to take water from streams and aquifers). To confound matters, expanding groundwater extraction around the world outcomes in dynamic salt water entrance in wells and aquifers. Rajasthan is the driest state of India, in which out of 15 basins only 2 basins are perennial. Due to unavailability of surface water in the state, groundwater plays an important role for all uses particularly as a drinking water source. The state dependence on ground water is 91% for drinking water. Therefore, state faces acute water crisis making Groundwater a centralized source of drinking water for millions of rural and urban families in Rajasthan. Unfortunately, in Rajasthan this precious source is facing the problem of salinity and nitrate contamination in most of the districts of the state. A total of 19 districts are affected and Bhilwara is said to be the worst.. Many reverse osmosis plants have been installed in Rajasthan for removal of nitrate from ground water. 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 nitrate 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 nitrate removal if total dissolved solids concentration is less than 5000 mg/ lt and percentage reduction of nitrate 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.

***Index Terms*—Nitrate, Membrane Capacitive Deionization(MCDI), Reverse Osmosis**

I. INTRODUCTION

With the expanding condition, the accessibility of clean water has turned out to be key innovative, social and conservative difficulties of the 21st century. Around 1.2 billion individuals, or just about one-fifth of the total populace, live in ranges of physical shortage, and 500 million individuals are moving toward this situation.1 Another 1.6 billion individuals, or very nearly one fourth of the total populace, confront financial water deficiency6. Consumable water and additionally water for farming and industry has turned out to be basic. We have been wasting and dirtying this valuable asset and are presently needing discovering taken a toll focused fresher innovations for recovering this profitable life-supporting fluid. Water shortage is among the principle issues to be confronted by numerous social orders and the water utilize has been developing at more than double the rate of populace increment3. Rajasthan is the driest state of India, in which out of 15 basins only 2 basins (Chambal and Mahi) are perennial. Due to unavailability of surface water in the state, groundwater plays an important role for all uses particularly as a drinking water source. The state dependence on ground water is 91% for drinking water. This precious source is facing the problem of salinity, fluoride and nitrate contamination in most of the districts of the state. Based on the WHO (World health organization) guidelines for drinking-water quality, about 56% of the water sources are un-potable in the state1. The state normally receives annual rainfall of 549.1 mm but 16 of the 33 districts got 20-60 per cent less last year. Almost all of Rajasthan suffers from the problem of high nitrate concentrations, ranging from 40 to1000 mg/l 4. A total of 19 districts are affected and Bhilwara is said to be the worst. Officials say most water reservoirs, dams and hand pumps have either dried or are rapidly losing water2. Many RO plants have been established in the state for removal of nitrate from groundwater. Rapid scaling and fouling of the membranes, and also high power consumption has lead to the need for an alternate technology. Membrane capacitive deionization is a new technology, which consumes less power and also the water recovery is much higher. 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 possible5. 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)5.

II. Working of Membrane Capacitive Deionization

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

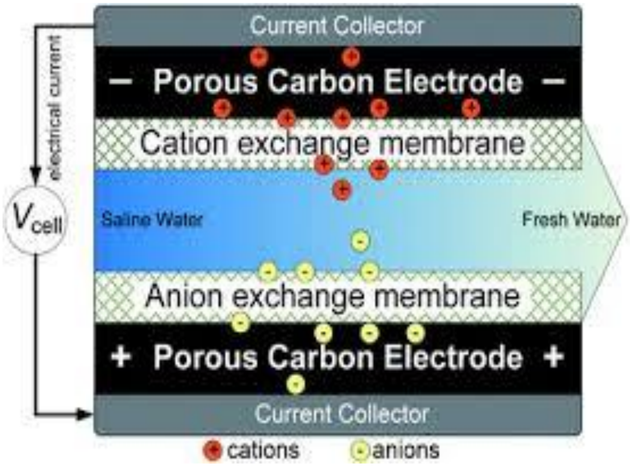

Figure 1 Membrane Capacitive Deionization

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 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.

III. Study Area

In India, Rajasthan is considered as a major nitrate affected state in the country (Gopal and Bhargava, 1982). Nitrate levels in ground waters of Rajasthan have caused a great concern particularly in arid and semiarid climates. Nearly the whole Rajasthan is suffering from the problem of high nitrates with concentration ranging from 40 to 1000 mg/L (Sudhir Kumar et al., 2002). Mathur and Ranganathan (1985) found nitrate concentration ranging from 45 - 613 mg/L at Jodhpur city. Nitrate concentration in ground water varied from 8 mg/l at Balesar to 199 mg/l at Baori, Osian. Exceptionally high concentration of 536 mg/l was observed at Mandore. Nitrate in excess of maximum permissible limit of 45 mg/l has been reported from parts of Osian, Bhopalgarh, Mandore and Luni blocks. In Jaisalmer, Nitrate concentration in ground water has been found to vary from 10 mg/l at Lawa to 229 mg/l at Khudi. In about 64% of the samples analyzed, nitrate in excess of the maximum permissible limit of 45 mg/l has been reported. The study was conducted for water samples from Raiko ki Basni, Charano ki Dhani, NPH Chowki, PWD colony of Jodhpur district and Ghantiyali, Kuria, Kishangarh (border areas) of Jaisalmer district.

IV. Methodology and Observation

Membrane Capacitive Deionization Pilot Plant was established at PWD colony of Jodhpur where the source of water was tube well in the colony and other samples were collected from different areas of Jodhpur and army areas of Jaisalmer district which were transported in tankers. These water samples were treated and the reduction of nitrate ion was observed, where the Current capacity(240A) was fixed. the power consumption of the MCDI plant also varies with the variation in the electric conductivity of water, hence it was also taken as the secondary parameter. Plant observations are mentioned in the table below:

- 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 the entire treatment process, the current was kept constant. The plant allowed the user to set desired percentage salt removal. By setting the desired percentage removal, the actual salt removal in the treated water was observed.

Table 1 Observed percentage removal for each set percentage removal for Nitrate for different source stations

Source station	Feedwater conductivity (µS/cm)	Feedwater Nitrate (mg/l)	Set Percentage removal			
			50%	75%	90%	98%
Charano ki dhani	8871	232	24.06	48.70	-	-
NPH Chowki	2462	222.12	36.97	66.75	78.84	86.04
Ghantiyali	1842	217	30.87	69.58	83.41	84.79
Raiko ki basni	5012	149	22.81	50.33	61.74	-
Kishangarh	2422	106	29.24	70.75	70.75	72.64
PWD Colony	1842	100.61	52.59	66.20	83.10	87.07
Kuria	2742	91	26.37	37.37	84.61	94.06

Water samplefrom different border areas of Jaisalmer district and some areas of Jodhpur was brought to the plant for testing. The machine was operated at different salt removal percentages, namely, 50%, 75%, 90% and 98%. It was observed that the plant was able to remove as much as 94% of the nitrate for Kuria water sample, while for other samples, with almost the same conductivity, the plant was found effective to remove about 85% of nitrate on an average. For sample Raiko ki basni, the plant could remove only upto 61.74% nitrate against the set removal of 90%. It was observed that for the water sample brought from Ghantiyali, the conductivity was 1842 µS/cm and Nitrate concentration was 217 mg/l, similarly the water sample brought from Charano ki dhani had conductivity of 8871 µS/cm, and the nitrate concentration was about 232 mg/l. While the machine was able to remove upto 84.79% of nitrate in the sample from Ghantiyali, the machine could only remove about 48% of nitrate from the Charano ki dhani sample, even when the nitrate concentration was almost same for both the samples. This indicates that when the conductivity of the water goes higher than 5000 µS/cm, the plant does not work that effectively, as it reaches its maximum current.

Table 2 Power consumption by CapDI plant during water treatment for varying nitrate concentration with set percentage removal is described in table below

Source	Feed water Nitrate (mg/l)	Power consumption for set percentage reduction (KWH)			
		50%	75%	90%	98%
PWD Colony	100.61	0.17	0.35	0.54	0.78
NPH Chowki	222.12	0.19	0.36	0.62	0.81
Kuria	91	0.19	0.36	0.62	0.84
Kishangarh	106	0.19	0.42	0.81	0.86
Ghantiyali	217	0.26	0.76	0.89	0.98
Raiko Ki Basni	149	0.26	0.89	0.98	-
Charano Ki Dhani	232	0.86	1.06	-	-

Table 3 Observations of various RO plants for almost similar nitrate concentrations in water as were in CapDI plant

S.No.	Source	Plant Capacity (LPH)	Feed Water Nitrate(mg/l)	Nitrate in outlet (mg/l)	Observed Percentage Reduction	Power consumption (KWH)
1	Shergarh	1000	119	9	92.43	4
2	khabra	1000	142	12	91.54	4
3	Baori	1000	90	6	93.33	4
4	Luni	500	256	8	96.87	3
5	Shetrawa	1000	290	15	94.82	4
6	Devrajgarh	500	208	12	94.23	3

From the above two tables, it is clear that the power consumed by the Reverse osmosis (RO) plant is much higher than the power consumed by Capacitive deionization plant, for the same nitrate ion concentration in the feed water. Although at some places it was observed that RO plant was able to remove nitrate ion slightly more than the capacitive deionization plant, but since the capacitive deionization plant was able to bring the nitrate concentration below the permissible limit, it was ignored because the power consumption was almost one third for the capacitive deionization than that of RO plant.

V. Conclusion

Nitrate removal capacity of the Membrane Capacitive deionization was analyzed for groundwater collected from different areas of Jodhpur district and border areas of Jaisalmer district of Rajasthan. The aim was to study the nitrate removal capacity of the membrane capacitive deionization technology. The power consumption capacity of the machine was also observed. Electric conductivity was taken as secondary parameter, as the power consumption and nitrate ion removal was highly affected by the electric conductivity of the feed water. During the process, it was observed that the machine attained salt reduction up to 90% when the electric conductivity was less than 5000 µS/cm, and for conductivity more than 5000µS/cm, the machine could only attain 48% salt reduction before the machine reached its maximum current capacity. Water samples from Charano ki dhani and NPH Chowki had almost similar nitrate ion concentrations, namely

232 mg/l and 222.12 mg/l respectively but the electric conductivity of Charano ki dhani was 8871 µS/cm and that of NPH Chowki was 2462 µS/cm. For these two samples it was observed that while the Cap DI plant was able to remove the nitrate ion from NPH Chowki water sample by 86%, it could only remove approximately 48% of the nitrate ion concentration from Charano ki dhani water sample, before reaching its maximum current capacity (240A).

The water recovery was observed to be 67% constant through out the whole process. When compared with RO plant, it was observed that the membrane capacitive deionization consumed only about 30% of the total power consumed by the RO plant, against the same nitrate ion concentration in the feed water.

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