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DRINKING WATER SUPPLY THROUGH REVERSE OSMOSIS DESALINATION PLANTS IN RAMANATHAPURAM DISTRICT OF TAMIL NADU, INDIA

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ABSTRACT

The population in Ramanathapuram district of Tamil Nadu State (India) faces potable water scarcity throughout the year in general and acute drinking water problems in lean periods of the year. To mitigate this problem, eleven reverse osmosis (RO) desalination plants were installed in problem villages in the district. General performance of these eleven plants and in-depth evaluation of two plants was undertaken to focus attention on the physico-chemical quality of water at various stages of treatment, present status with respect to operation and management (O & M) financial implications and overall management in a rural situation.

The study indicated that performance of these RO plants was satisfactory in removing high TDS, though the efficiency deteriorated with time. The average utilization of these RO plants since their installation was 46% as compared to the design capacity, mainly due to non-availability of power in rural areas, time lapsed in repairs of pumps, and non-availability of spares. The average capital cost/m^3 and O & M cost/m^3 of product water from these eleven plants works out to Rs. 27.40 and Rs. 44.50 respectively; when plants are utilized as per the design capacity. These costs are high and not affordable by the rural population. The RO plants were socially acceptable since the population was satisfied with the treated water quality. © 1999 Published by Elsevier Science Ltd on behalf of the IAWQ. All rights reserved

KEYWORDS

Brackish and saline ground water; cartridge filter; RO membrane.

INTRODUCTION

Ramanathapuram is a coastal district in Tamil Nadu state of India with an annual average rainfall of 800 min. Large scale storage of rain water in deep ponds is not feasible as the soil strata below 5-7 m is saline due to the infiltration of marine water, and storage in shallow ponds lasts only for a few months. Ground water is brackish or saline in nature and not suitable for drinking purposes. The district has no perennial potable water sources. The ground water, therefore, needs treatment for the removal of dissolved solids. Reverse osmosis (RO) is one of the technologies in vogue to convert brackish/saline water into potable water. The RO technology is a pressure driven membrane separation process, less energy intensive than other desalination processes and suited for small capacity plants. RO plants with capacities ranging from 10 m^3/day to 50 m^3/day have been installed in Ramanathapuram district for the desalination of ground water.

METHODOLOGY

A study was undertaken to evaluate the functioning of the eleven RO plants installed in Ramanathapuram district for the supply of drinking water to villages. Chemical and physical analysis of feed, product and reject water for parameters which require immediate attention was carried out in a field laboratory set-up for the purpose. Detailed analysis of feed, product and reject water was carried out at the NEERI Laboratories at Nagpur.

SALIENT FEATURES OF RO PLANTS

The technical features of the plants are summarised in Tables 1 and 2. These plants are designed to use brackish/saline ground water as feed water to produce product water having TDS < 500 mg/L with a recovery of 45-55%. Raw water needs pre-treatment before passing through RO membranes. Pre-treatment consists of (a) sand filter of graded quartz sand and (b) imported polypropylene cartridge filter. The cartridge filter traps particles above 5 microns from raw water before it enters the RO assembly. The plants have a membrane cleaning facility. Necessary chemicals, acids, EDTA (sodium salt), phosphoric acid, citric acid, ammonium hydrogen fluoride, caustic soda, sodium tripolyphosphate, trisodium phosphate for cleaning of RO membranes have been provided with an injection pressure of 4 kg/cm^2. Post-treatment includes pH adjustment by addition of sodium carbonate (1%). The system can withstand temperatures between 5 and 45°C. High pressure pumps are imported and have a discharge pressure of 24 kg/cm^2. Spiral wound thin film composite (TFC) configuration polyamide membrane elements made by FilmTec Corporation, The Dow Chemical Co., USA have been used in the plants. The average life of RO membranes is three years. Operating pressures are so adjusted as to obtain 70 to 80% of the designed product water volume. The RO membranes need chemical cleaning when yield of product water reduces by 10% of the design value.

The two RO plants at the villages of Sikkal and Melasirupodhu were studied in detail. Sikkal is situated on the southern part of Ramanathapuram district about 35 km from Ramanathapuram town. The village population is 4718 as per 1991 census. This village has been provided with a RO plant of 50 m^3/day capacity using a 150 m deep bore well as raw water source. Melasirupodhu is about 9 km from Sikkal village. RO plant of 30 m^3/day capacity with a 130 m deep tube well as raw water source was commissioned near Sikkal-Paramkudi Road, 2 km away from the village in December 1991. The physico-chemical quality of the water at various stages of treatment is presented in Table 3.

PERFORMANCE OF RO PLANTS

The performance of Sikkal plant was found to be satisfactory. Operating pressures and differential pressures were found to be in the design range (Table 1). Product water yield was 55% of feed water. Rejection of TDS was found to be 91%. Immediately after commissioning of the plant, the salt rejection was 98-99% (Fig. 1). As regards physico-chemical quality of the product water during the evaluation, except for TDS and chloride all parameters were within the desirable limits of BIS:10500. The utilization of the plant was 30.4% of the design capacity. This drastically decreased the yield of product water from the plant and increased the cost of production.

Though operating and differential pressures were found to be in the design range, the performance of Melasirupodhu plant was inferior to that of the Sikkal plant. Product water yield was about 50% of feed water. Rejection of TDS was 89%. Treated water had a chloride concentration 1.5 times higher than the desired value and sodium in excess by 30 mg/L over the WHO limit. The quality of product water indicates that the RO membrane needs replacement. Plant utilization was only 36.4% of the design capacity.

Table 1. Salient features of the design and performance of RO Plants in Ramanthapuram District

Sl. No.	Parameters	Melasirupodhu		Sikkal	
		Design Value	Observed Value	Design Value	Observed Value
1	Product water output (m^3/hr)	1.875	1.875	3.125	3.125
2	Product water yield (percent of feed water)	45-55	49.5	45-55	55
3	Operating pressure range (kg/cm^2)	15-25	16-18	15-25	20-21
4	Differential pressure across the membrane (kg/cm^2)	1-3	1-2	1-3	1-2
5	Plant utilisation (hours/day)	16	5 hrs* 48 mts	16	4 hrs* 54 mts

* Average valus, since installation of the plants

The performance of eleven RO plants is summarised in Table 2. Evaluation of these plants showed that raw water TDS at some places is as low as 2,400 mg/L and as high as 17,100 mg/L. Karisalpuli plant was not operated since October 93 as the product water was not found to be potable. Initially all the plants had product water TDS below 500 mg/L. However, after three years of operation, in five plants TDS was more than 1000 mg/L indicating deterioration in product water quality. Average utilization of these plants since their installation was 46%. This resulted in enhancing the product water cost to exorbitant levels and decreased the per capita availability. The utilization of four plants out of eleven was so low that these plants were not able to provide minimum of 3 lpcd required by each individual for drinking purposes alone.

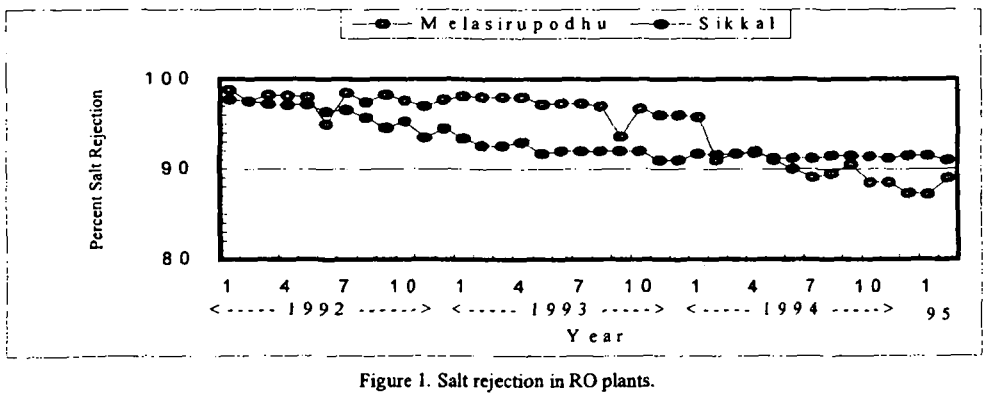

Figure 1. Salt rejection in RO plants.

The average capital cost/m^3 and O & M cost/m^3 of product water from eleven plants works out to Rs. 27.4 and Rs. 44.5 respectively (Table 4), when plants are utilised as per design. It is not affordable by individual village water supply schemes. The average per capita capital cost/annum and average per capita O & M cost/annum for eleven plants works out to Rs. 97 and Rs. 15 7 respectively with 10 lpcd supply. These costs are not affordable by the village population.

Table 2
Performance of RO Plants in Ramanathapuram District

Sl. No.	Parameter	Location of the Plants											
		Karisalpuli	Kundukulam	Vanniakudi	Nallirukkai	Enathi	Posseri	Karumal	Melasirupodhu	Sikkal	Valinokkam	Serandai	Total / Average
1.	Date of commissioning	15.11.89	15.2.90	15.5.90	16.5.90	15.5.90	5.12.91	13.12.91	30.12.91	7.1.92	3.4.92	15.12.91	-
2.	Design capacity (m^3/day)	50	20	20	30	10	20	20	30	50	30	20	300
3.	Population covered	4,093	2,007	1,752	3,450	1,394	1,624	2,099	4,156	4,718	3,045	1,806	30,144
4.	Design lpcd	12.2	10	11.4	8.7	7.2	12.3	9.5	7.2	10.6	9.8	11.0	10
5.	Plant utilisation* (percent)	23.8	42.9	69.7	59.4	34.3	52.4	64.1	36.4	30.4	25.3	68.5	46.1
6.	Actual product water output (m^3/day)	11.9	8.6	13.9	17.8	3.5	10.5	12.8	10.9	15.2	7.6	13.7	138.3
7.	Actual lpcd	2.9	4.3	7.9	5.2	2.5	6.4	6.0	2.6	3.2	2.5	7.5	4.6
8.	TDS (mg/L)												
	a. Raw water	13,400	17,100	5,600	3,300	11,330	4,200	2,400	7,480	5,620	4,300	7,200	-
	b. Reject water	28,200	34,300	11,800	7,800	20,500	9,000	5,300	12,900	11,500	9,700	15,000	-
	c. Product water												
	i. Jan. '92	1,160	1,005	435	385	630	330	140	125	155	285	450	-
	ii. Feb. '95	1,680**	1,310	840	1,330	1,375	1,110	880	780	545	600	890	-
9.	Percent salt rejection (Feb. '95)	87.5	92.3	85.0	60.0	87.9	73.6	63.3	89	91	86.1	87.6	-

* Average value, since installation of the plants

** Product water was found not potable, hence plant not operated since 11.10.92

Table 3

Physico-chemical Characteristics of Feed, Product and Reject Water from RO Plants in Ramanathapuram District

Sl. No.	Parameter	Melasirupodhu				Sikkal				BIS : 10500 (1991)
		Feed Water	Product Water	Reject Water	Rejection (Percent)	Feed Water	Product Water	Reject Water	Rejection (Percent)	Desirable Limit
1.	pH	7.1-7.5	6.5-6.9	7.6-7.9	-	7.1 – 7.5	6.5 – 6.9	7.7 – 7.9	-	6.5 – 8.5
2.	Turbidity (NTU)	0.7	ND	1.0	100	0.1	ND	0.2	100	5
3.	TDS	7,480	780	12,900	89.6	5, 620	545	11,500	90.7	500
4.	Total Alkalinity ($CaCO_3$)	572	50	1,100	91.2	300	25	600	91.7	200
5.	Total Hardenss ($CaCO_3$)	1,500	140	2,700	90.7	945	80	1.900	91.5	300
6.	Calcium ($CaCO_3$)	425	40	700	90.6	305	25.0	600	91.8	-
	Calcium (Ca^{++})	170	16	280	90.6	122	10.0	240	91.8	75
7.	Magnesium ($CaCO_3$)	1,075	100	2,000	90.7	640	55.0	1,300	91.4	-
	Magnesium (Mg^{++})	260	25	486	90.7	155	13.0	316	91.4	30
8.	Sodium (Na^+)	2,240	230	3,700	89.7	1,800	180	3,500	90.0	200 (WHO)
9.	Potassium (K^+)	20	2.1	39	89.5	11.0	1.2	21	89.1	NA
10.	Chloride (Cl^-)	3,410	345	5,590	89.9	2,780	280	5,420	89.9	250
11.	Sulphate (SO_4^{2-})	980	95	1,800	90.3	600	45	1,250	92.5	150
12.	Nitrate (NO_3^-)	12.3	1.3	21	89.3	0.3	Nil	0.6	100	45
13.	Fluoride (F^-)	0.5	0.06	1.0	88.0	0.5	0.06	1.0	88.0	0.6 – 1.2
14.	Silica (SiO_2)	3.0	0.3	5	90.0	2.5	0.25	4.8	90.0	NA
15.	Total Iron (Fe)	0.35	ND	0.8	100	0.3	ND	0.6	100	0.3
16.	Manganese (Mn)	0.04	ND	0.07	100	0.02	ND	0.04	100	0.1
17.	Langelier Index	0.5 - 0.9	- 1.9	1.5 - 1.8	-	0.1 – 0.5	- 2.4	1.3 – 1.5	-	-

All values except pH, and turbidity are in mg/L; ND - Not detected; NA - Not available

Table 4
Potable Water Cost in Rupees from RO Plants in Ramanathapuram District (As per Design Utilization Period of the Plants)

Sl. No.	Parameter	Location of the Plants											
		Karisalpuli	Kundukulam	Vanniakudi	Nallirukkai	Enathi	Posseri	Karumal	Melasirupodhu	Sikkal	Valinokkam	Serandai	Total / Average
1.	Capacity (m^3/day)	50	20	20	30	10	20	20	30	50	30	20	300
2.	Population covered	4,093	2,007	1,752	3,450	1,394	1,624	2,099	4,156	4,718	3,045	1,806	30,144
3.	**Capital cost (in Million Rupees*)**												
	a. Plant cost (including membranes)**	2.099	0.828	0.828	1.433	0.68	0.922	0.922	1.094	1.532	1.094	0.922	12.354
	b. Membrane elements (20%)	0.42	0.185	0.165	0.286	0.13	0.184	0.184	0.22	0.306	0.22	0.184	2.464
	c. Civil works**	0.566	0.384	0.178	0.456	0.22	0.384	0.371	0.413	0.397	0.221	0.436	4.016
	Sub-total	3.075	1.377	1.171	2.175	1.03	1.49	1.477	1.72	2.235	1.535	1.542	18.827
	d. Contingencies (10%)	0.307	0.137	0.117	0.217	0.1	0.149	0.147	0.17	0.223	0.153	0.154	1.874
	Sub-total	3.382	1.514	1.288	2.392	1.13	1.639	1.624	1.89	2.458	1.688	1.696	20.7
	e. Finance charges (7%)	0.236	0.106	0.09	0.167	0.079	0.115	0.114	0.13	0.172	0.118	0.119	1.446
	f. Spare parts (10% of plant cost)	0.21	0.083	0.083	0.143	0.068	0.092	0.092	0.11	0.153	0.109	0.092	1.235
	Total capital cost	**3.828**	**1.703**	**1.46**	**2.702**	**1.277**	**1.846**	**1.838**	**2.13**	**2.73**	**1.915**	**1.907**	**23.336**
4.	Amortization 11.68% [@ 8% interest & 15 yrs. plant life] (in Million Rupees)	0.447	0.199	0.17	0.315	0.15	0.22	0.214	0.249	0.325	0.223	0.223	2.735
5.	**Total O&M cost**** (in Million Rupees)	**0.542**	**0.42**	**0.42**	**0.47**	**0.367**	**0.293**	**0.293**	**0.366**	**0.274**	**0.366**	**0.292**	**4.103**
6.	Cost/capita/annum (in Rupees)												
	a. Capital	109	99	97	91.3	107.6	135.5	102	60	69	73.2	123.4	97
	b. O&M	132.4	209	240	136.2	263	180	139.6	88	58	120.2	161.7	157.1
7.	Cost of water (Rs./m^3)												
	a. Capital	24.5	27.2	23.3	28.8	41.1	30.1	29.3	22.7	17.8	20.3	30.5	27.4
	b. O&M	29.6	57.5	57.5	42.9	100.5	40.1	40.1	33.4	15	33.4	40	44.5
	c. Capital and O&M	54.1	84.7	80.8	71.7	141.6	70.2	69.4	56.1	32.8	53.7	70.5	72.0

* Pound Sterling 1.00 = Rupees 65/-

** As per the actual expenditure incurred by Rajiv Gandhi National Drinking Water Mission, Ramanathapuram

Total O&M cost includes charges for chemicals, labour, power and other miscellaneous maintenance expenses

GENERAL OBSERVATIONS AND CONSTRAINTS FACED IN OPERATION AND MAINTENANCE OF THE RO PLANTS

RO desalination technology is an advanced and cost intensive technology. Installation of these plants in remote villages of India poses many difficult problems in operation and maintenance which are summarised below:

- The raw water pumps, low pressure pumps, and high pressure pumps break down very often. These cannot be repaired locally or at district level. As a result, if plants remain in shut-down condition for a longer period, chemical preservation of the membranes is needed to prevent their fouling. This requires specialised skill and training. Failure to do so results in the fouling of the membranes.

- Electric power supply is erratic in the villages and is hardly available for more than 8-10 hours a day. Voltage variations and power cuts are more or less a daily phenomenon. This necessitates installation of captive power generators. This makes the cost of energy very high.

- Serious iron fouling results from the oxidation or corrosion of inline materials, therefore, plant components should be made of non-ferrous materials like PVC.

- Reject water contains high concentration of salts. The disposal of the reject water in the villages poses a difficult problem of land pollution. Conveying it to safer discharge places involves a financial burden.

- Fortnightly and monthly chemical cleaning of the RO membranes is the most crucial step to keep the system in efficient condition and avoid formation of scales of calcium and magnesium on the RO membranes. Proper care and maintenance of these membranes has been found to be very difficult in village conditions.

- Low utilization of the plants due to various operational reasons, the most important being pump failure and power failure, enhances the cost of product water to exorbitant levels, which makes the cost unaffordable by the local rural population.

CONCLUSIONS

The product water of Sikkal plant has TDS close to the BIS desirable limit of 500 mg/L. Melasirupodhu plant product water has one and a half times more TDS than the desirable limit, with sodium and chloride ions higher than the BIS standards, indicating the need to replace the membrane.

The efficiency of the RO plants in salt rejection has gone down slowly from 99% to less than 90% in three to four years of operation.

The average utilization of the plants varied from 30 to 70% due to various reasons yielding only 3.5 to 18 m^3/day of product water as against the installed capacity of 10-50 m^3/day.

Due to under-utilization of the plant capacities the annual capital and operating costs are very high and are unaffordable by the rural population.

It is observed that the capital cost (Rs. 27.4/m^3) of water is not high compared to the O & M cost (Rs. 445/m^3). The average cost of product water of the eleven plants is about Rs. 72/m^3.

The views of the consumers were obtained by interviewing them individually. The consumers were satisfied with the quality of the product water.

Skilled operation and maintenance is a prerequisite for RO plants which is seldom available under rural situations.

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