Reverse Osmosis Desalination as an Alternative Water Resource Project for Drinking Water Production a Case Study

[1]Avin J. Kajekar, [2]B. M. Dodamani
Department of Applied Mechanics and Hydraulics
National Institute of Technology Karnataka,
Surathkal Mangalore, India

[3]Arun M. Isloor
Department of Chemistry
National Institute of Technology Karnataka,
Surathkal Mangalore, India

***Abstract*—Gadag district located in northern part of Karnataka state in India has very high hardness and other contaminants in groundwater. The groundwater is an important source to meet the water requirement for domestic use, minor irrigation and industries. Many people use water directly from the municipal bore wells and are exposed to the increased risk for cardiovascular disease, growth retardation, reproductive failure, and other health problems due to the hardness in drinking water. Reverse Osmosis (RO) technology is adopted for purification of groundwater by building community scale water treatment plants. As part of the research project the components and design of the RO water purification plant are studied and economic feasibility analysis is conducted. We find that community scale RO plants are an effective approach to mitigate the potable water scarcity of Gadag district and are economically feasible within 3 years of installation. As an outcome of the study, it is recommended to incorporate ultrafiltration (UF) pre-treatment unit to reduce bio fouling of the RO membranes and further improve cost effectiveness of RO water purification.**

***Keywords*—Reverse Osmosis; Desalination; Drinking water; Gadag district**

I. INTRODUCTION

Water is the lifeblood of this planet. All known forms of life require water to survive. Humans use water for much more than basic sustenance and use it to grow crops, generate power, transport people and goods, cultivate medicines and manufacture products. The availability of potable water has become a global challenge due to the increasing growth in water demand and decreasing quality of available potable water. The quality of water in natural sources is being adversely impacted due to indiscriminate discharge of contaminated wastewater into these sources without adequate treatment. Studies are being taken up to efficiently treat non-potable and contaminated water for personal and industrial use. With increasing water crisis across the world and advent of new technologies it is now required to implement alternative water resource projects [1] such as desalination, purification of contaminated water, and use of treated wastewater and Stormwater (water reuse).

Membrane Technology has potential to solve the demands for increased quantity as well as quality of water. Membranes can be broadly defined as a semi-permeable barrier to the flow of suspended, colloidal, or dissolved solids in any solvent. Membrane processes used for potable water treatment are reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF). The lower limits of RO, NF, UF, and MF particle rejection are 0.0001 µm, 0.001 µm, 0.01 µm, and 0.1 µm, respectively. Membranes are being used for brackish and seawater reclamation (desalination) as well as to remove contaminants from surface and groundwater. They are also being used for treatment of wastewater for indirect potable reuse and for production of industrial process water and ultrapure water. Membrane filtration technologies are considered one of the most effective approaches due to their high efficiency, broad range of contaminant rejection, scalability, small footprint and environmentally friendly approach. Membrane processes are now the preferred approach for desalination due to their lower energy consumption and higher recovery leading to lower cost of produced water. Membrane processes are a proven success in the field of water treatment and desalination [2].

The case study of water supply in Gadag district in North Karnataka is taken up for the present study. Groundwater currently being used in the district is not suitable for human consumption due to high hardness and other contaminants. There is also a possibility of groundwater contamination by toxic heavy metals and hazardous organic dye pollutants due to it being an industrial zone and handloom cluster. Reverse Osmosis (RO) technology is adopted for purification of groundwater. Study of the RO water purification plant is conducted and economic feasibility is analysed. Recommendations are provided for further process optimization.

A. Water Resources in Gadag district

Gadag district is located in northern parts of Karnataka and situated in between north latitudes of 15° 15' and 15°45' and east longitudes of 75°20' and 75°47'. As per 2011 census, the Gadag District had a population of 971,952. The district falls under semi arid tract of the state and it is categorized as draught prone. Average annual rainfall is 613 mm [3]. Ground water is an important source to meet the water requirement for domestic use, minor irrigation and industries. Groundwater is a dynamic resource getting recharged annually primarily from the rainfall and is vulnerable to various developmental activities and prone to deterioration in quality and quantity.

Gadag district has a large number of households without municipal treated piped water connections and thus it is difficult to ensure supply of safe water for drinking, washing and other human activities. Typically water is accessed individually from community borewells directly for all activities without any treatment or disinfection before consumption. The groundwater in Gadag has very high hardness and total dissolved solids (TDS) and is unfit for human consumption. Large areas of groundwater in the district are also contaminated with Fluoride and Nitrate. People directly using this water are exposed to the adverse effects and have increased risk for cardiovascular disease, growth retardation, reproductive failure, and other health problems due to the hardness in drinking water [4]. RO water treatment is adopted to purify the highly contaminated groundwater and make it fit for drinking purpose. Community scale water purification plants make the projects cost-effective and easier to maintain.

B. *Reverse Osmosis (RO)*

Reverse Osmosis (RO) technology uses applied pressure greater than osmotic pressure of the feed to move water from region of high concentration to low concentration through a semi-permeable membrane [5]. The applied pressure forces water to move in the opposite direction of the nature flow that occurs in osmosis as shown in Fig. 1.

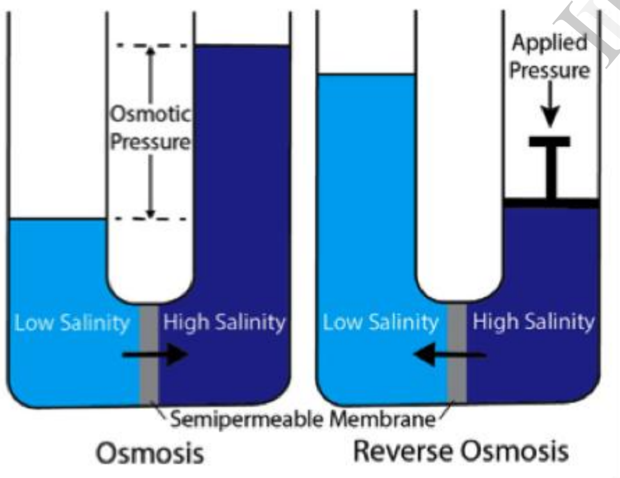

Fig. 1. Reverse Osmosis process [5].

RO membranes act as a physical barrier and thus are able to remove contaminants other than salts including heavy metals, pesticides, hazardous dyes, biological contamination etc. Membrane based RO is now the preferred approach to desalination due to its lower energy consumption and higher recovery leading to lower cost of produced water. Membrane based RO systems represent 80% of all desalination plants worldwide [6]. They are a proven success in decentralized potable water production [2].

II. METHODOLOGY AND DISCUSSION

A. *Study of RO water purification at Gadag district*

RO water treatment plants capable of delivering 2000 L/h of treated water are setup at 4 locations in Gadag with similar design and are being used to treat Groundwater from borewells which are pumped to surface by submersible pumpsets. The quality of feed water from the bore wells are tested and results shown in TABLE I. From the feed water quality analysis, we find very high Total Dissolved Solids (TDS) exceeding the acceptable limit of 500 mg/L for drinking water [5].

TABLE I. FEED WATER QUALITY PARAMETERS

Parameter	Test Sites			
	Raw water Site 1: GG	*Raw water Site 2: AB*	*Raw water Site 3: HN*	*Raw water Site 4: SS*
Color	Hezen Unit 9	Hezen Unit 16	Hezen Unit 15	Hezen Unit 14
Turbidity (NTU)	10	18	17	16
pH	7.1	7.7	6.8	7.5
Electric Conductivity (µS)	2281.97	4639.99	6009.98	3089.99
TDS (mg/L)	1246.50	2596.43	3515.11	1734.75
Total Hardness (mg/L)	890	1368	1500	776
Calcium (mg/L)	254.29	390.86	428.57	221.71
Magnesium (mg/L)	105.95	162.86	178.57	92.38
Chloride (mg/L)	245	684	750	430
Fluoride (mg/L)	0.8	0.9	1.8	0.8
Sulphate (mg/L)	80	160	509	153
Nitrates (mg/L)	21	50	165	60
Free Carbondioxide	168.84	55.45	491.02	52.09
Alkalinity	845	1396	1550	826
Salinity	2.7	7.8	4.9	5.1

The quality deterioration and contamination of groundwater can be attributed partly to the natural means of decomposing of host rock/aquifer by prevailing weather condition over the years or indiscriminate dumping of wastes on the land and usage of chemical fertilizers in the agricultural land by human activities [3]. It is also an Industrial cluster as identified by Central Pollution Control Board, prone to pollution from industries. Due to many handloom and textile industries there is also possibility of hazardous dye pollution.

The components of the RO plant are shown in Fig.2, and the design is as follows:

Study sponsored by M/s. GENIO Management (P) Limited, Mangalore.

- First the raw feed water from the bore well, is pumped via a submersible pumpset to the raw water storage tank, which is made of Polypropylene (PP). Since, the RO treatment plant is designed for output of 2000 L/h and 50% recovery, the raw water tank capacity is chosen as 5000 litres.

- Single-stage centrifugal pump with flow rate of 4.0 m^3/h forces raw water through the different pre-treatment stages.

- In first stage of pre-treatment, the raw water is filtered though a dual-media filter pressure vessel made of Fiber Reinforced Plastic (FRP) consisting of sand, gravel and pebbles as filter media. The filter is down-flow type and a special multi-port valve enables us to change the direction of water flow for backwashing the filter. Backwashing helps clean the clogged filter media and regenerates the water flow rate and should be performed on a daily basis.

- The raw water then enters the down-flow type anthracite filter pressure vessel also made of FRP. Anthracite is a type of hard mineral coal and this filter helps remove organic particles, color and smell from the feed water. It is recommended to backwash the anthracite filter on a daily basis.

- Due to very high hardness in the feed water, a separate cation ion-exchange resin based water softener is provided as the next step of pre-treatment to reduce the hardness content of feed water before it reaches the RO membrane. Sodium contained in the resin is exchanged for magnesium and calcium ions that are contained in the RO feed water. The resin that gets depleted during the water softening process can be regenerated by concentrated brine (NaCl) solution, which is provided in a separate tank.

- In an RO system, there is high possibility of scaling i.e. deposition of particles on the membrane surface, due to sparingly soluble compounds present in feed water. At this stage of pre-treatment, an antiscalant dosing system injects a calculated amount of antiscalant chemical to feed water to prevent scaling. The antiscalant dosing is based on mineral analysis at this point, which is calculated from the feed water analysis and the system recovery factor.

- After antiscalant dosing, the RO feed water is fed through 2-stages of 20-inch polypropylene based micron cartridge filters of 10 micron in first stage and 5 micron in second stage. Microfiltration pre-treatment ensures that the feed water being fed to RO has most of the larger size impurities removed to prolong life of the membrane.

- The feed water is pressurized for the RO process by a centrifugal multi-stage (12 stage) high-pressure pump to overcome the osmotic force of brackish water and enable reverse osmosis to obtain pure water. There is a bypass arrangement provided for controlling system pressure and recovery ratio. The pressure in the system is measured using a bourdon type stainless steel pressure gauge.

- The pressurized feed water is fed into 2 parallel FRP membrane modules. The membranes are polyamide based Thin Film Composite (TFC) membranes in 8 inch wide spiral wound configuration manufactured by General Electric Company (GE). The operating pressure of the membranes is 10-12 kg/cm^2. The system under study is designed for 50% recovery and is designed as a single pass system. An online flow indicator continuously monitors the RO permeate and reject flow rate. The RO permeate is stored in a stainless steel tank of 2000 litres capacity and the reject is discharged into the local sewers.

- The end user is charged Rs.1.00 for 10 litres of RO purified. When the end user inserts coins of appropriate denomination, the system activates a delivery pump and solenoid valve for limited time duration. The delivery pump forces the water stored in the stainless steel pure water tank through a single stage 5 micron filter and UV disinfection as post-treatment before dispensing water through a stainless steel tap.

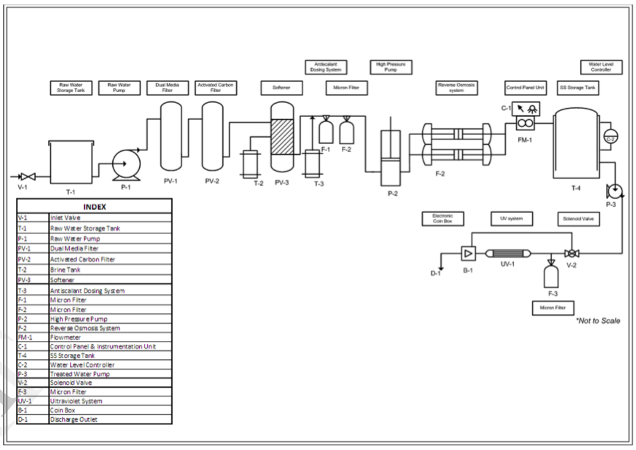

Fig. 2. RO water purification plant at Gadag district.

The quality parameters of RO treated water are tested and results shown in TABLE II. From the results, we find all quality parameters are within the acceptable range for drinking water.

TABLE II. RO PURIFIED WATER QUALITY PARAMETERS

Parameter	**Test Sites**			
	Pure water Site 1: GG	***Pure water Site 2: AB***	***Pure water Site 3: HN***	***Pure water Site 4: SS***
Color	Hezen Unit 0	Hezen Unit 2	Hezen Unit 0	Hezen Unit 3
Turbidity (NTU)	0	3	0	4
pH	6.9	6.8	6.7	6.9
Electric Conductivity (µS)	154.00	172.99	148.98	68.00
TDS (mg/L)	83.99	93.59	81.92	36.78
Total Hardness (mg/L)	48	70	40	28
Calcium (mg/L)	13.71	20.00	11.43	8.00
Magnesium (mg/L)	5.71	8.33	4.76	3.33
Chloride (mg/L)	24	40	20	14
Fluoride (mg/L)	0.5	0.2	0.4	0.1
Sulphate (mg/L)	3	7	2	3
Nitrates	0	2	0	1

Parameter	Test Sites			
	Pure water Site 1: GG	***Pure water Site 2: AB***	***Pure water Site 3: HN***	***Pure water Site 4: SS***
(mg/L)				
Free Carbondioxide	11.82	7.92	20.74	3.02
Alkalinity	47	25	52	12
Salinity	0	0	0	0

Hence, we can conclude that RO is an effective technology for purifying contaminated and non-potable water for human consumption.

B. Economic feasibility analysis of RO water purification at Gadag district

The economic feasibility analysis of RO water purification plant is conducted based on following:

- The RO plant is setup by putting in 20% of capital cost as initial investment and 80% of capital cost by availing bank loan at rate of 12% per annum, repayable in 3 years i.e. 36 months.
- Electricity for running the RO plant is charged at Rs.15.00 / KWh.
- The end user is charged Rs.1.00 for 10 liters of RO purified water.
- The RO plant is operated on average 6 hours / day.

TABLE III. ECONOMIC FEASIBILITY ANALYSIS

Sl. No.	RO Plant installation, operation and maintenance	
	Item	*Amount (Rs.)*
1	Capital cost of RO plant	650,000.00
2	Initial investment	130,000.00
3	EMI / year	207,252.00
4	Operator salary / year	36,000.00
5	Consumables & parts cost / year (Filter media, resin, filters, chemicals, pipes and fittings, electrical items etc.,)	33,800.00
6	Electricity cost / year	98,550.00
7	Total operation & maintenance cost / year	171,600.00
8	RO Membrane cost once every 3 years	40,000.00
9	Total cost for installing & running the system for 3 years	1,306,556.00
10	Total revenue generated in 3 years	1,314,000.00
11	Net balance at the end of 3 years	+ 7,444.00

Thus, we find that the RO plant becomes economically viable within 3 years of installation.

C. UF module as pre-treatment for RO

The study of RO water purification plant at Gadag district reveals some opportunities for process optimization and cost savings. In the RO plant at Gadag, there is no effective barrier against microorganisms and dissolved organics in the feed water before the RO Process. Though Microfiltration (MF) pre-treatment is being used, due to its larger pore size it is not very effective in filtering bacteria and other organic matter which can adsorb on the RO membrane surface and become food source for build-up of microbes [7]. Bio-fouling is a major concern and drastically reduces life of the expensive RO membranes due to more frequent cleaning and earlier replacement. The water purification process can be further optimized by integrating ultrafiltration (UF) as a membrane based pre-treatment unit before the RO process.

Ultrafiltration (UF) is a well-established membrane technique and has been effectively used as RO pre-treatment. UF separates larger size particles based on size exclusion or particle capture. UF is capable to completely filter colloidal contaminants, bacteria and most of the viruses, thus allowing total removal of turbidity and a considerable reduction of Silt Density Index (SDI) resulting in a stable operation of RO process [7]. UF can be applied in either cross-flow or dead-end mode.

Nanocomposite membranes have been found to exhibit unique and varied properties such as lower energy requirements [7] and increased anti-fouling properties [8]. Further, hollow fiber membrane modules have high filtration rate, high rejection rate and small footprint and have been used for a variety of applications including drinking water purification [9]. Thus it may benefit to develop and introduce nanocomposite UF hollow fiber membrane unit as pre-treatment to reduce costs and optimize the water purification process.

III. CONCLUSION

RO water purification plant at Gadag district is studied in detail. Water quality parameters of untreated bore well water and RO purified water are tested and reported. Economic feasibility analysis is conducted for setting up and operating the RO water purification plant. Recommendations are provided for process optimization. The following conclusions are noted:

- RO technology is an effective means to purify non-potable water and make it potable for human consumption.
- Community scale RO plants are appropriate and cost effective in Gadag and other districts of India with similar water supply challenges. The RO water purification plants become economically viable within 3 years of installation.
- UF can be used as pre-treatment unit before the RO process to increase life of the RO membranes and thus reduce operation and maintenance costs.
- In view of enhancing membrane properties with lower energy requirements and increased anti-fouling ability it may be suitable to develop nanocomposite hollow fiber UF membrane module.

ACKNOWLEDGMENT

We thank National Institute of Technology Karnataka, Surathkal for financial assistance to travel abroad for conducting research on new membrane development. Avin. J. Kajekar thanks M/s. GENIO Management Private Limited, Mangalore for sponsoring the field trips to Gadag district and providing an opportunity to study the RO water purification plants.

REFERENCES

[1] J.S. Thomas, and B. Durham, "Integrated Water Resource Management – looking at the whole picture," Desalination, vol. 156, pp. 21-28,2003.

[2] M.P. Varbanets, C. Zurbrügg, C. Swartz, and W. Pronk, "Decentralized systems for portable water and the potential of membrane technology," Water Research, vol. 43, pp. 245-265, 2009.

[3] Central Ground Water Board, Ministry of Water resources, Government of India, "Ground water information booklet – Gadag District, Karnataka," 2012.

[4] P. Sengupta, "Potential Health Impacts of Hard Water," International Journal of Preventive Medicine, vol. 4, ed. 8, pp. 866-875, August 2013.

[5] N.C. Wright, and A.G. Winter, "Justification of community-scale photovoltaic-powered electrodialysis desalination systems for inland rural villages in India," Desalination, vol. 352, pp. 82-91, 2014.

[6] F. Macedonio, E. Drioli, A.A. Gusev, A. Bardow, R. Semiat, and M. Kurihara, "Efficient technologies for worldwide clean water supply," Chemical Engineering and Processing, vol. 51, pp. 2-17, 2012.

[7] S. Jamaly, N. N. Darwish, I. Ahmed, and S. W. Hasan, "A short review on reverse osmosis pretreatment technologies," Desalination, vol. 354, pp. 30-38, 2014.

[8] X. Qu, P.J.J. Alvares and Q. Li, "Applications of nanotechnology in water and wastewater treatment," Water Research, vol. 47, pp. 3931-3946, 2013.

[9] C.Y. Feng, K.C. Khulbe, T. Matsuura, and A.F. Ismail, "Recent progresses in polymeric hollow fiber membrane preparation, characterization and applications," Separation and Purification Technology, vol. 111, pp. 43-71, 2013.