Chronic Kidney Disease of Unknown Aetiology in Sri Lanka: An Implication of Optimizing Recovery Ratio of Brackish Water Reverse Osmosis Plant

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Abstract— Drinking water is an essential for human beings. At times, the fresh water from the sources of water in the environment such as streams, wells, and other water bodies cannot be used as drinking water because of the high content of dissolved salts and solids. This is most prominent in areas where water is scarce and areas where fertilizers and chemicals are used for different day-to-day processes such as agriculture. With a high level of environment contamination for a prolong period, the chemicals get into the underground water sources. In rural areas of Sri Lanka, mainly in the district of Anuradhapura, the majority of the people are prone to Chronic Kidney Diseases of Unknown aetiology (CKDu). Reverse osmosis technique is used to remove the dissolved solids from the fresh water and bring it to a drinkable level. Brackish Water Reverse Osmosis (BWRO) plants are present in an industrial scale to provide drinking water from brackish water, but at a higher cost. The main aim of this project is to develop a BWRO plant at a lower operating cost with a high recovery ratio to be implemented in areas where Total dissolved solid (TDS) levels are above the SLS standard (500 mg/L), and where even brackish water is scarce.

Keywords: ***drinking water, brackish water, reverse osmosis, cost, recovery ratio***

I. INTRODUCTION

When considering the planet earth 70% of the area is covered with water bodies but 2.5% of it is fresh water which is suitable for human use and drinking purposes, and only 1% of that is easily accessible, the other is saline water and ocean based. In most countries, lack of fresh water is a huge crisis. Even in the dry zone of Sri Lanka, the freshwater crisis is inevitable with an average rainfall of 1000 mm (Wanasinghe et al., 2018) for a limited period of 3 months and a drought period for 5 months during the mid-year. The water needed for the agricultural activities is obtained using the tank cascade system, which is to be sufficient for the drought period, once filled during the rainy season. But with time it has been observed that Dental fluorosis and Chronic Kidney Diseases of Unknown etiology (CKDu) is a major health issue as a non-communicable disease mainly in parts of North Central, North, North Western, Central, Eastern, Uva, Southern (Dissanayake, 2020) which had resulted in high morbidity and mortality among farmers, agricultural laborer's and their families between the ages 40-60 due to the changes in the drinking water parameters by the contamination of agricultural activities as a probable cause. The dialysis treatment, and kidney transplantation are the only cure for the CKDu patients with a high cost or causing death within two years of getting prone for 80% of the patients.

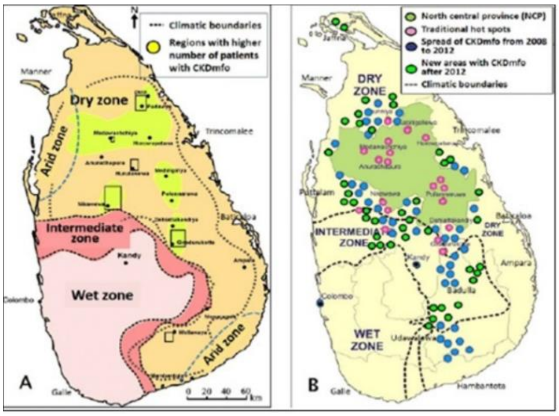

Figure 1.Areas of CKDu spread (Wanasinghe et al., 2018)

The Brackish Water Reverse Osmosis (BWRO) is the process of obtaining purified drinkable fresh water by reverse osmosis through a specially designed semi-permeable membrane comprising of pre-treatment, post treatment and a cleaning cycle. The feed water temperature, concentration, flow rate, and pressure difference in sides of the semi-permeable membrane are the major factors effecting the process. Reverse osmosis is a technique that extract fresh water from sea water, which is used on board naval vessels to meet the freshwater requirement. The Government of Sri Lanka initiated a program to provide safe drinking water CKDu affected people by importing BWRO plants through National Water Supply and Drainage Board (NWSDB) of Sri Lank, Non-Governmental Organizations (NGO) and establishment of distribution centres in the North Central Province (NCP). Amidst the failure of that program due to practical reasons of unavailability of skilled personnel for defect rectification, repairs and absence of compatible spare parts in the local market. Then, with the involvement of the Sri Lanka Navy, a sustainable solution of in-house BWRO plants was introduced by utilizing the SLN operators to supply safe drinking water to the rural community (Dissanayake, 2020). Consequently, SLN BWRO plants project has been expanded up to 900 plants and providing safe drinking water to more than 2 million people at CKDu impacted areas in the country.

The absence of drinking water quality parameters within acceptable levels (SLS 614: 2013) is the main cause for the spread of CKDu in Sri Lanka. Elimination of CKDu can be done by establishment of BWRO plants. But the Recovery ratio of existing BWRO plants is calculated and identified as around (40-50) % of feed water (Indika et al., 2021). Further, it is understanding that present recovery is not adequate compared to the ground water yield at the dry zone in Sri Lanka. A 75% recovery ratio is a mandatory requirement of a BWRO plant as per the United States Environmental Protection Agency (EPA) due to the scarcity of fresh resources.

II. DESIGN FEATURES

North Central Province (NCP) is the most CKDu affected area in the country. Therefore, 407/ Meegassegama village, Talawa divisional secretariat, Anuradhapura District of the NCP was selected as the study area in this research. The process would differ according to the implementation area because the quality of brackish water, contamination levels, and total dissolved solids (TDS) levels differ from area to area. Then the feed water characterization should be done for the identification of the TDS levels in the feed water for the membrane selection process. In the BWRO process to increase the efficiency by determining the membrane design calculating the effective operative feed water inlet pressures at each stage and the flow rate. The input pressures of pumps should be calculated with trial and error through the closed loop monitoring of the output and inputs by considering the head losses. The whole process is to be automated as PID to control input, output pressures, with the operation of directional valves to maintain constant flowrate, freshwater feed system for membrane flushing at the starting process. The implementation area was selected for the requirement of a low-cost brackish water reverse osmosis (BWRO) plant with the feed water characteristic carried out. The observation of the existing BWRO system with two pressure vessels arranged as single stage parallel configuration was done by measuring the output flows of permeate and concentrate, manually using measuring instruments. The main challenge of coming up with the membrane arrangement was discussed. Mainly the stage array module arrangement and the closed-circuit desalination (CCD) were the most suitable way used to increase the recovery ratio as well as to increase the permeate water quality.

The closed-circuit desalination (CCD) involved higher number of valves and pumps, hence our main objective is to improve the recovery ratio at a lower cost, by the trials carried out on the test rig the concentrate staging array system with two modules had a high recovery ratio. The readings for the output flows of permeate and concentrate were taken manually but even with high pressure pump turned on, the recovery ratios were very low due to the absence of the required osmotic pressure for the RO membrane. The osmotic pressure is developed using flow restrictors.

A. Feed Water Characterization

A feed water characterization of water samples taken from the implementation area was done to identify the water quality in the area.

Following details were obtained through the water quality tests conducted.

National Water Supply and Drainage Board – Water quality test report

Date and time of water sample collected: 0900 hrs on 2020.08.04

Date and time of water sample handed over: 1025 hrs on 2020.08.04

Location of water sample: 407, Meegassegama, Kiralogama

Table 1. Feed Water Characteristics

Parameters	According to SLS 614: 2013 standards		Results Relevant to the Sample	Method of Testing
	Units	Maximum Value		
Physical Characteristics				
Colour	Hazen	15	15	APHA 2120 C
Turbidity	NTU	2	3.0	APHA 2130 B
pH value	25°C ± 0.005°C	6.5-8.5	7.3	APHA 4500-H^+ B
Chemical Characteristics				
TDS	mg/l	500	227	APHA 2540 c
Chloride (Cl-)	mg/l	250	70	APHA 4500 Cl –B
Total bases (as $CaCO_3$)	mg/l	200	140	APHA 2320 B
Total Solubility (as $CaCO_3$)	mg/l	250	130	APHA 2340 C
Nitrate (as NO_3^-)	mg/l	50	0.44	APHA 4500 NO_3^-, E
Nitrite (as NO_2^-)	mg/l	3	0.01	APHA 4500 NO_2^- B
Sulphate (as SO_4^{2-})	mg/l	250	04	APHA 4500 SO_4^{2-} B
Fluoride (as F^-)	mg/l	1.0	0.42	APHA 4500 F^- D
Total Phosphate (as PO_4^{3-})	mg/l	2.0	0.28	APHA 3500 PE
Iron (as Fe)	mg/l	0.3	0.09	APHA 3500-Fe B
Free Ammonia (as NH_3)	mg/l	0.06	-	PAN Method

Sample Drawn by S and D Chemicals (PVT) Ltd.

Test on Heavy Metals

Sample Received date : 21/09/2020

Report Issued Date : 21/09/2020

Table 2. Heavy Metal Indication

Parameter	CAS Number	Result(mg/l)	Limit of Detection (mg/l)
Arsenic as As	7440-38-2	ND	0.05
Cadmium as Cd	7440-43-9	ND	0.05
Copper as Cu	7440-50-8	ND	0.05
Chromium as Cr	7440-47-3	ND	0.05
Iron as Fe	7439-89-6	ND	0.05
Lead as Pb	7439-92-1	ND	0.05
Magnesium as Mg	7439-95-4	8.51	0.10
Manganese as MN	7439-96-5	ND	0.05
Nickel as Ni	7440-02-0	ND	0.05
Sodium as Na	7440-23-5	27.93	0.10
Potassium as K	7440-09-7	0.26	0.10
Calcium as Ca	7440-70-2	31.78	0.10
Silver as Ag	7440-22-4	ND	0.05

B. Pressure Vessel Arrangement

Initially, the pressure vessel/membrane arrangement, which was in two stage parallel configuration, where the water from the pre-treatment stage is fed into two parallel pressure vessels, the concentrate, and the permeate output is also obtained parallelly from the two pressure vessels were modified and tested on the BWRO test rig present at the marine laboratory of KDU as a two stage series arrangement, where the water from the pre-treatment is fed into one pressure vessel, the output concentrate from the first vessel is fed into the second pressure vessel and both permeates from the first stage and the second stage are combined as the final output. Following readings were obtained without controlling the pressure of the concentrate output using a globe valve.

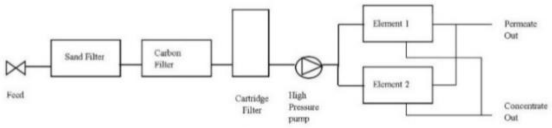

Figure 2. Pressure vessel arrangement before modification

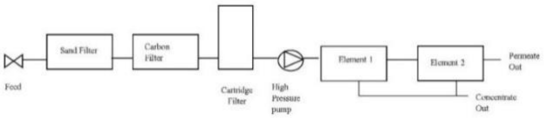

Figure 3. Pressure vessel arrangement after modification

Table 3. Results obtained without concentrate pressure control

Description		Permeate Out (ml)	Concentrate Out (ml)	Feed water (ml)	Recovery Ratio (%)
Before Modification	Without pressure pump	125	4000	4125	3.030303
	With pressure pump	140	4000	4140	3.381643
After Modification	Without pressure pump	350	4000	4350	8.045977
	With pressure pump	600	4000	4600	13.04348

The concentrate output needs to be controlled using a globe valve to build up pressure at the output of the pressure vessel to limit the concentrate flowrate and increase the permeate flowrate increasing the overall recovery ratio per fixed amount of feed water.

C. Recovery Ratio Calculation

The calculation of the recovery ratios for the above module Arrangements are as follows.

- Qfn = Feed flow to RO-n (m^3/h)
- Qpn = Permeate flow of RO-n
- Qbn = Concentrate flow of RO-n
- R = Recovery ratio

Single stage module arrangement

$$Qf1 = Qp1 + Qbl$$

$$R = 100 * \frac{Qp1}{Qf}$$

Multistage parallel module arrangement

$$Qf1 = Qp1 + Qp2 + Qp3 + Qbl + Qb2 + Qb3$$

$$R = 100 * \frac{Qp1 + Qp2 + Qp3}{Qf1}$$

Multistage series module arrangement

$$Qf1 = Qp1 + Qbl$$

$$Qf2 = Qp1 = Qp2 + Qb2$$

$$R = 100 * \frac{Qp2}{Qf1}$$

Multistage series and parallel module arrangement

$$Qf1 = Qp1 + Qbl$$

$$Qf2 = Qp1 = Qp2 + Qb2$$

$$Qf3 = Qb1 + Qb2 = Qp3 + Qb3$$

$$R = 100 * \frac{Qp2 + Qp3}{Qf1}$$

Permeate flow (Qp)

$$Qp = Am * Lp * (\Delta Pm - \sigma \Delta п)$$

- Am = Total membrane surface area
- Lp = Hydraulic permeability of the membrane (depends on the type and product of the membrane)
- ΔPm = Average transmembrane pressure
- σ = Reflection coefficient of membrane.
- $\Delta п$ = Average osmotic pressure difference between feed $\Delta \eta f$ and permeate $\Delta \eta p$.
- $(\Delta Pm - \sigma \Delta \eta)$ = Average trans membrane net driving pressure, NDP.

Number of membrane elements (Ne)

$$Ne = \frac{Qp}{f * Se}$$

- Qp = Design permeate flow
- F = Flux
- Se = Membrane element surface area

Number pressure vessels (Nv)

$$Nv = \frac{Ne}{Nepv}$$

- Ne = Number of membrane elements
- Nepv = Number of elements in a pressure vessel

- The number of elements and the number of pressure vessels may vary with the manufacturer due to the variation of the Membrane element surface area (Se) and the Number of elements in a pressure vessel (Nepv).

D. Implementation at Talawa (Anuradapura District)

The BWRO facility was built at 407/ Meegassegama village, Talawa divisional secretariat, Anuradhapura District of the North Central Province. 520 families are living in this village.

Figure 4. BWRO Facility building

E. Membrane Installation

The existing BWRO was a single stage single element arrangement figure 6. Therefore, 2nd membrane was purchased and installed serially to this BWRO plant figure 8.

Salient Features of Membarne

a. Modle : LP 440
b. Working Pressure (Max) : 600 psi
c. Working Temperature of feed water (Max): 45 °C
d. Operating PH : 2-11
e. Chlorine concentration : < 0.1 ppm
f. Maximum SDI : 5

The membrane installation is a very delicate procedure if processed wrongly it would result in membrane damage and water leaks. First, the flow side of the membrane should be identified by the marking then the pressure vessel end caps must be adjusted to decide the orientation of the pressure vessel, to define the inlet port, permeate out and concentrate out. When inserting the membrane inside the pressure vessel, the end caps are fixed accordingly at the end of the flow side which contains the 'O' ring to be placed at last to the vessel. Shampoo was applied as lubrication before inserting the element. Then the ½ inch sockets were placed at the feed inlet, permeate out, concentrate out ports, and end cap to the remaining inlet port as there are 2 ports per end cap of the pressure vessel.

Figure 5. Inserting the new BWRO membrane into the pressure vessel

The tightening of the sockets at the end caps with an appropriate amount of thread sealant and PVC gum is necessary to avoid leaks as the membrane is pressured at high pressures. The leaks would also create a drop in pressure and a messy environment around the plant, even creating possibilities for electrical short circuiting. The locking mechanism of the end caps was different from what we have come across. The existing connections were observed and the flow rate of the concentrate was measured before removing it for modification figure 6 & 7.

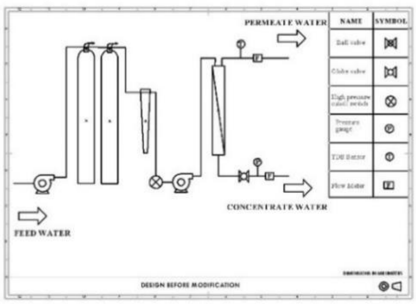

Figure 6. Design before modification

Figure 7. Observation of single stage arrangement

Figure 8. Time taken to fill 4L of concentrate with single stage membrane arrangement

As seen above, only 19.5s was taken to fill 4L amount of concentrate, our main objective was to increase. Which would decrease the flow rate and the amount of concentrate output, simultaneously increasing the permeate output. The union joints at the feed inlet, permeate output, and the concentrate output were detached, and the connections were modified to support the new additional membrane to the system to be modified as two stage series configuration. In addition to the plumbing, the frame structure was modified to hold the second pressure vessel. There was a difficulty of attaching second pressure vessel as there were no compatible brackets, but the team was able to adjust an existing bracket to able to fit the new membrane while supporting the lower part via a temporary fixture, till a suitable bracket is available for installation in figure 9 & 10.

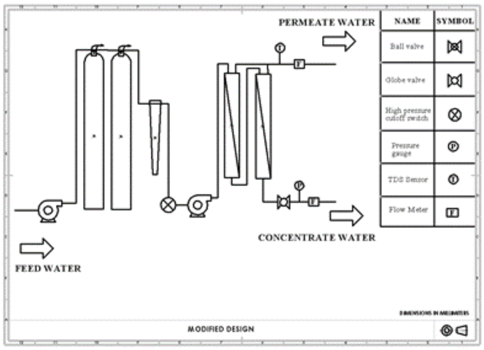

Figure 9. Modified design

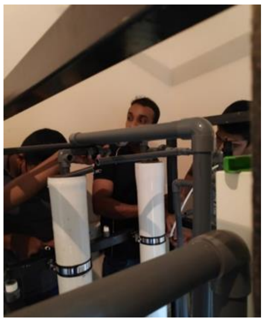

Figure 10. Modifying the plumbing arrangement

Same time, rejected water was tested by hand held conductivity meter and pH meter in Table 4.

Table 4: Comparison of Reject Water Parameters vs Sri Lankan Standard 614

Parameters	Results	SLS 614
pH	7.3	6.5-8.5
Electrical Conductivity	918 ppm	750 ppm
TDS	588 mg/l	500 mg/l
Hardness	518 mg/l	250 mg/l

III RESULTS AND DISCUSSION

Recovery Ratio

The membranes can be used for relatively a longer duration than usual by performing cleaning cycles in a pre-defined period, chemically and fresh water backwashing. If the process is slowed down or if the recovery ratio is decreased due to membrane clogging, the manufacture has provided with an option of using the membrane in reverse flow direction by using the "O" Ring in the opposite side groove. The modification of the pressure vessel arrangement was successful in increasing the recovery ratio by more than 50% which was present before with the single stage array arrangement by two stage series array arrangement. But the desired 75% recovery ratio was not obtained. The input and the output of the pressure pump were bypassed with a ball valve by creating a pressure difference and a flow path to supply for the water deficit created at the stage array input figure 11 & 12. Then the flow rate of the concentrate was as to fill 4L time occurred was 43.5s. Where the flowrate has decreased compared to the 19.5s that occurred previously with the use of single stage system. The resultant concentrate water also had more salt texture relative to the concentrate obtained before the modification figure 8.

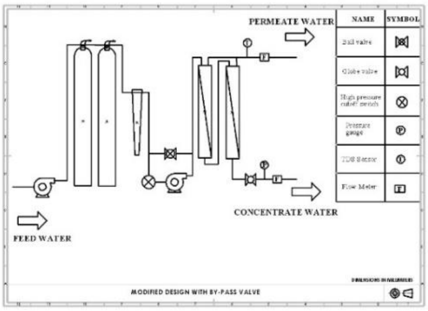

Figure 11. Modified design with by-pass valve

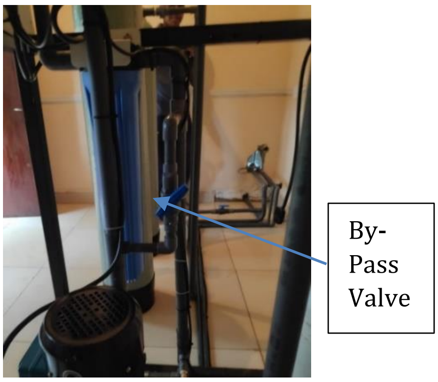

Figure 12. By-Pass valve modification

Figure 13. Observation of Concentration flow after modification

When calculating the recovery ratio, we considered a time of 1 minute for calculations.
For a 1-minute time.

Feed water volume = 25.26 l

Before Modification,

Concentrate Volume = 12.9 l

Therefore, Permeate volume = 25.26 – 12.9 = 12.36 l

Recovery Ratio = 12.36/25.26 ×100% = 48.9%

After Modification,

Concentrate Volume = 6.21 l

Therefore, Permeate volume = 25.26 – 6.21 = 19.05 l

Recovery Ratio = 19.05/25.26 ×100% = 75.4%.

The pH value of reject water was 7.3 and revealed that the pH value was within SLS 614. Further, TDS and Hardness of reject water were above specified SLS 614. Moreover, electrical conductivity was a bit high compare to SLS 614.

IV. CONCLUSION

This resulted in a huge benefit to the villages of Meegassegama by increasing the recovery ratio which would in return reduce the cost per litre of water obtained and reduce in feed water wastage through concentrate. The feed water saving would be mostly affected on times of drought where water is scarce, and the feed water sources are drying up. Recommend to reuse reject water and improve the recovery ratio upto 100% Table 4.

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AUTHOR BIOGRAPHY

[1]Cmde (E) MCP Dissanayake, CEng (India) is currently performs as the Head of Department (Marine Engineering) and hold 2 No's patents for his research papers published so far. He is an inventor and published 06 publications on Brackish Water Reverse Osmosis application, Fan Boat Building, and Oscillation Water Column, Ocean Wave Eenrg Converter. He was the Director in Research & Development at Sri Lanka Navy and has received commendations in number of occasions from Commander of the Navy, HE the President of Sri Lanka for his innovation. Further, he was awarded with prestigious, Japanese, Sri Lanka Technical Award for his own developed low-cost Reverse Osmosis Plant, to eliminate Chronic Kidney Disease from Sri Lanka. Moreover, he has a vast exposure on marine diesel engines and possesses a Masters degree in Marine Engineering from Autralian Maritime College, University of Tasmania, Australia.