Performance Analysis of Reverse Osmosis Desalination Plant Study Case of BBRI Plant

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Abstract

Desalination using seawater resources has been a cornerstone in meeting both human and industrial water demands for several decades. Some well-known methods are thermal desalination and membrane desalination. Among these, membrane desalination stands out, employing reverse osmosis (RO) technology, wherein seawater is pressurized and forced through a semi-permeable membrane to produce purified water. Black Bear Resources Indonesia (BBRI), which operates in the chemical industry relies on RO technology to cater its desalination requirements within the manufacturing facility. Notably, BBRI's desalination plant is equipped with both Seawater Reverse Osmosis (SWRO) and Brackish Water Reverse Osmosis (BWRO) modules. In the SWRO unit, the Hydranautic SWC-6 Max membrane is employed, while the BWRO unit features the Hydranautic ESPA-2 LD membrane. Both modules adopt the spiral wound configuration utilizing polyamide composite material. To determine the reliability of factory operations and dependability, a comprehensive performance analysis of the SWRO and BWRO units is imperative. This analysis encompasses critical parameters such as Recovery Rate, Membrane Flux, Percent Rejection, Concentration Rejection, and Specific Energy Consumption (SEC). Notably, performance degradation in both SWRO and BWRO systems primarily stems from membrane fouling, scaling phenomena, and the natural aging of the membranes.

Keywords: Desalination, Membranes, SWRO, BWRO, BBRI, Performance Analysis, Specific Energy Consumption, Fouling, and Scaling.

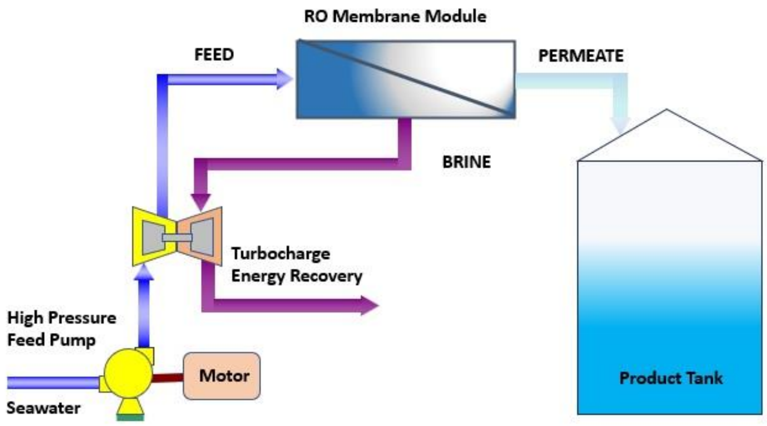
1. Introduction

Water treatment and purification are the procedure of getting rid of unfavourable chemicals, natural contaminants, as well as suspended solid from water. The aim is for deliver water for certain application. Desalination has developed a management water alternatively resource by allowing use of oceans, the greatest reservoir in the world. Sea water desalination technology reachable for decades and dominated the international industry specifically due to the outstanding abundance of saltwater resources, but the process has always been expensive, energetically, and economically. The origin of the energy necessary to produce water is mainly from the electrical systems that are isolated on islands, different on each island and on the mainland, which causes differences in the emission factor depending on its energy mix.

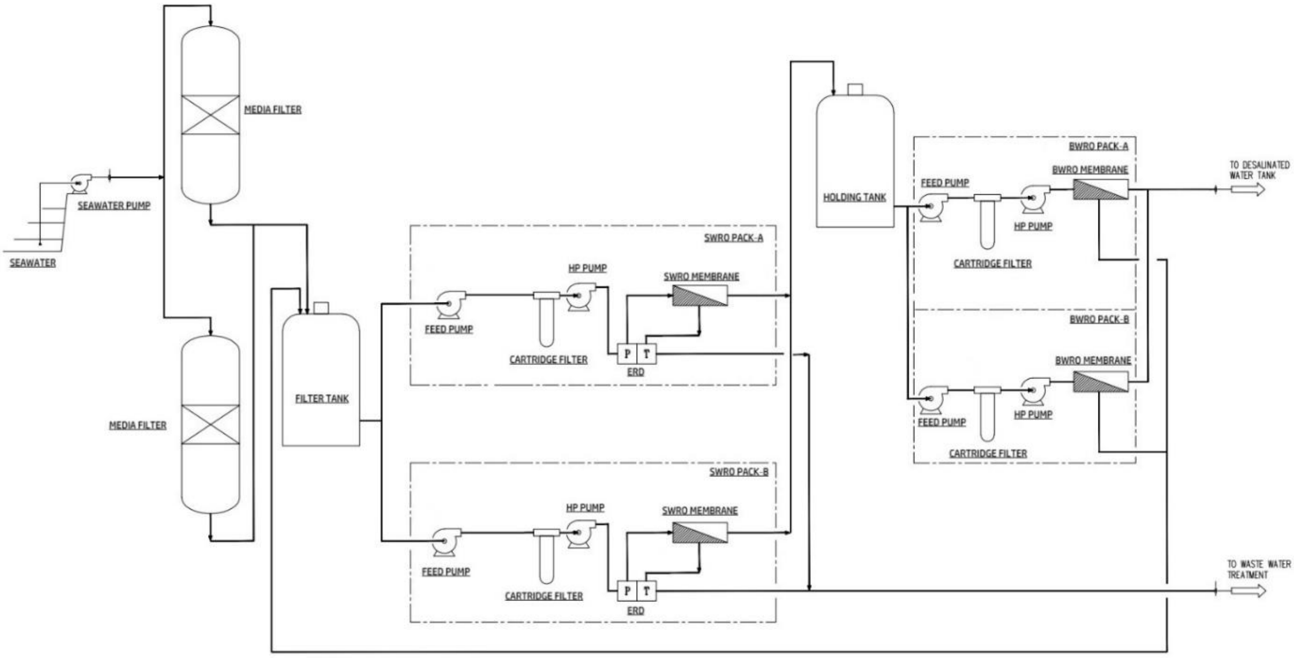
There are several types of desalination technology, primary method of desalination includes thermal processes, such as distillation and membrane processes such as reverse osmosis (RO) and electrodialysis. The membrane-based desalination technology has been widely used in the field of desalination because of low energy consumption, high efficiency, and ease of operation. While there are multiple membrane materials that can be selected as core components during desalination procedure. Black Bear Resources Indonesia (BBRI) is a chemical company in Indonesia located at Bontang – East Kalimantan Province using Reverse Osmosis technology to convert sea water into desalination water uses for industrial purposes. Water consumption is a critical utilities item for production. Reducing water production have impact overall plant operation, therefore performance of desalination plant is important to evaluate on periodically base. Performance of reverse osmosis desalination plant is calculated and evaluated on different operational parameters by putting them under keen observation and derived that how productivity of the plant is maintained to get better results.

2. Description of BBRI Reverse Osmosis Plant

Osmosis is physical phenomenon by which two liquids, in different salinity concentrations, separated by semi permeable membrane, come into contact, and tend to even themselves out. The liquid with the lower salinity concentration crosses the membrane toward that with highest salinity concentration. This process inverted in reverse osmosis desalination technology. Seawater as raw material, high salinity concentrated solution, forced through the membrane by adding pressure, on the other side as permeate obtain salt-free water, while back on the first side the remaining water still holds the salt that the membrane prevented from passing through.



BBRI desalination plant consists of Sea Water Reverse Osmosis Plant (SWRO) and Brackish Water Reverse Osmosis Plant (BWRO), both of RO plant using polymer membrane-based materials named Composite Polyamide. SWRO plant consists of two pressure vessels, each of vessels consisting of six membrane elements, while BWRO plant also have six membrane elements with only single pressure vessels. Sea water as raw material for SWRO filtered before feed SWRO plant and then permeate product of SWRO plant become feed inlet for BWRO plant.



3. Performance Analysis

Several operating parameters are used to see the performance analysis of RO desalination. In general, RO performance analysis is used to see the ability of the membrane to convert seawater to fresh water and how much energy has been used. To determine the performance of membrane, value of recovery rate, percent rejection, rejection concentration, and permeate flux need to calculate and evaluate. Specific energy consumption (SEC) calculation is another key performance analysis to understand how efficient or wasteful desalination plant is running.

Performance of RO Plant also can be determined by product quality, measure by conductivity in unit µS/cm. Compared to raw material from seawater, product water quality is far lower than seawater conductivity as known seawater conductivity reach >45,000 µS/cm and SWRO product is <1500 µS/cm, for BWRO product is <20 µS/cm. Below Table 1 is RO Module specification. Performance analysis of BBRI Plant taken on February 2023 from SWRO unit A & B and BWRO Unit B.

Table 1. RO Module Specification

Description	SWRO	BWRO
Design Capacity	210m^3/day	178m^3/day
Element Type	Spiral Wound	Spiral Wound
Membrane Active Area	40.9m^2	37.1m^2
Membrane Brand	Hydranautic SWC-6 MAX	Hydranautic ESPA-2 LD
Material (Vessel / Element)	Fibre Reinforce Plastic/ Composite Polyamide	Fibre Reinforce Plastic/ Composite Polyamide
Package Unit Vessel Number Total Element	2 Units (SWRO A & B) 2 vessels 12 elements (2 vessels/ unit,	2 Units (BWRO A & B) 1 vessel 6 elements (1 vessel/ unit,

	6 elements/vessel)	6 elements/vessel)
Liquid Raw Material	Sea Water	SWRO permeate
Recovery Ratio	40%	80%
Percent Rejection	99.8% (99.7% minimum)	99.6% (99.5% minimum)
Raw Conductivity	>45,000 µS/cm	<1,500 µS/cm
Product Conductivity	<1500 µS/cm	<20 µS/cm

3.1 Recovery Rate

Recovery rate is the percentage of amount product flow compared to the feed water raw material. High recovery rate means more clean water production and less wastewater generated. Lower recovery rate percentages indicate a problem with the membrane which may be caused by fouling or scaling, and if the recovery rate exceeds the manufacturing design, there is possibility of damage to the membrane. BBRI SWRO plant using Hydranautic SWC-6 MAX membrane have maximum 40% recovery rate while BWRO recovery rate is 80% using Hydranautic ESPA-2 LD membrane. Recovery rate can be calculated if permeate flow and feed flow are known, following equation and calculation.

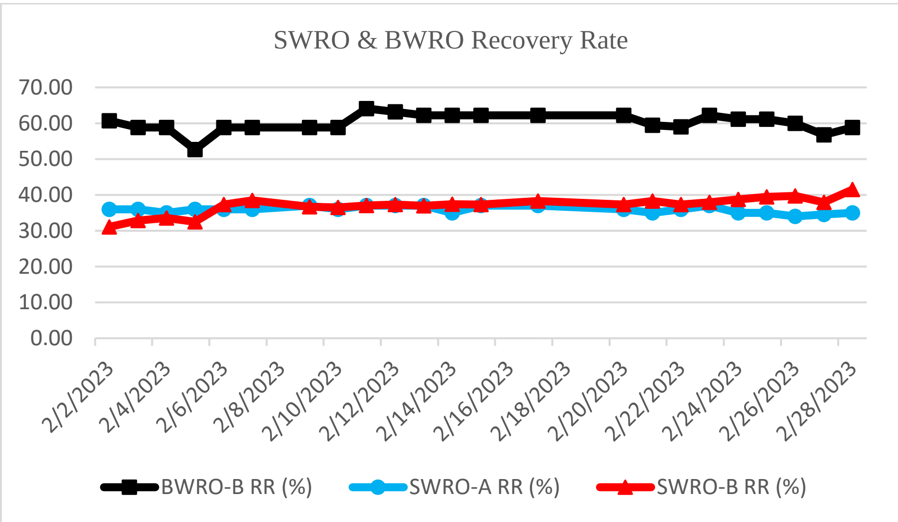
Recovery rate $= \frac{Qp}{Qf} \times 100$ .... (1)

Feed flow (Qf) = 283 LPM

Permeate flow (Qp) = 99 LPM

$= \frac{99}{283} \times 100$

= 34.98%



Membrane fouling and scaling are the main problem for RO plant operation because they significantly affect permeate membrane performance and desalination productivity. Membrane fouling is a serious problem related to SWRO membrane operation, biological fouling is the most difficult to prevent and control, several factors such as the concentration and specification of micro-organisms contained in the seawater, the content of easily biodegradable compounds in the water, the concentration of nutrients and the balance between organic compounds. Also, the temperature of water source. For this reason, chlorine injection needed to prevent biological growth.

Changes in recovery rate are influenced by many things such as the quality of the raw material, the amount of raw material flow, pressure feed and the number arrangements of membrane element. From the data showing that SWRO-A average recovery rate is 35.89% and SWRO-B is 37.02% while the target recovery rate as the specification is 40%. BWRO-B average recovery rate is 60.12% while the target recovery rate as the specification is 80%. Small-scale reverse osmosis has a small number of membrane elements so that the recovery rate percentage is also lower compared to many membrane elements. The percentage recovery rate can be increased by reducing the rejection flow; however, this can result in a decreasing quality of permeate production, an increase salt passage, a burden on the membrane element thereby shortening the life of the membrane, which results in an increase in chemical cleaning costs.

3.2 Membrane Flux

Average flux is used to express the amount of water that passes through the reverse osmosis membrane element during given time, usually measured in unit Gallon Feet Day (GFD) or Liters Per Square Meter Per Hour (LPM^2/H). Higher flux means more water passing through the RO Membrane. RO systems are designed to operate within a certain flux range to ensure the flow of water through the RO membrane is neither too fast nor too slow. With design capacity of SWRO 6.6m^3/h, using membrane SWC-6 MAX Hydranautic, with a total of 12 membrane elements, the surface area of each membrane is 40.9 m^2, average flux value is 13.5 LPM^2/H.

Regardless of the feed salinity, the influence of the flux value is linearly dependent on the hydraulic pressure, mean membrane feed pressure. To obtain a high flux value, higher hydraulic pressure required to distribute the feed water. In addition, the higher feed salinity requires higher pressure to overcome the osmotic pressure on the membrane. Following is the equation (2) & calculation of average flux of SWRO BBRI Plant if permeate flow is 99 LPM, actual membrane flux performance in February is 12.44 LPM^2/H for SWRO-A and 13.33 LPM^2/H for SWRO-B.

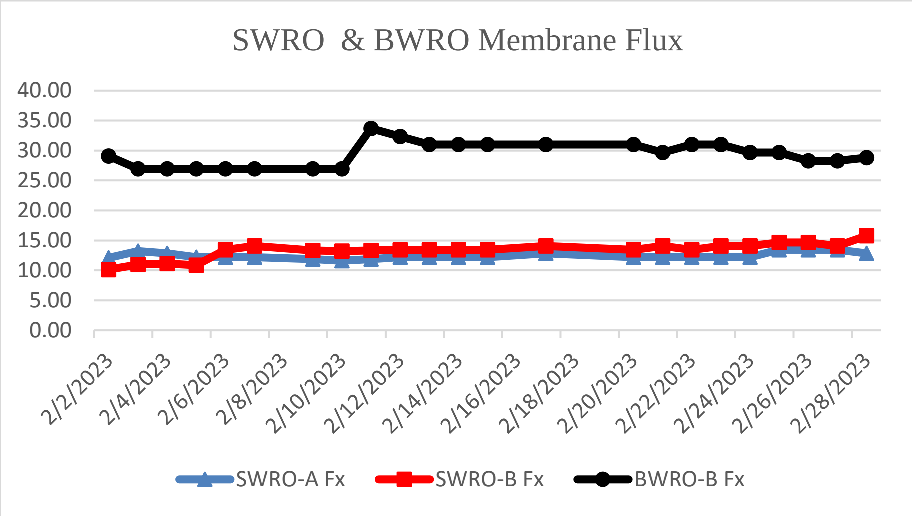
$$\text{Average system flux (Fx)} = \frac{Qph}{St} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$\text{Hourly totals permeate flow (Qph)} = 99 \times 60$$

$$\text{Total membrane surface (St)} = 12 \times 40.9$$

$$= \frac{5940}{490.8}$$

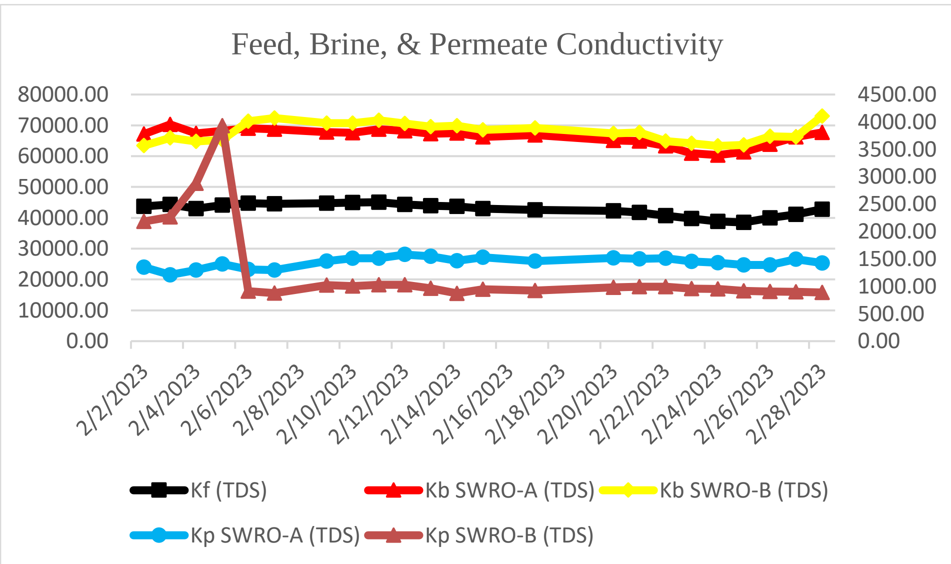
$$= 12.10 \text{ LPM}^2\text{/H}$$



Adequate flux is necessary for efficient operation, but overly high flux can lead to membrane fouling and reduced membrane lifetime. Achieving a balance between sufficient flux for productivity and controlled flux to maintain membrane healthiness is crucial in RO plant. BWRO design capacity 7.41 m^3/h, using membrane Hydranautic ESPA-2 LD, with a total of 6 membrane elements, the surface area of each membrane is 37.1m^2, average flux value is 33.2 LPM^2/H. Actual membrane flux performance in February is 29.36 LPM^2/H.

3.3 Brine Salinity/ Reject Concentration

The brine salinity or reject concentration refers to the concentration of dissolved salts and other impurities are in the brine stream that is produced because of RO water purification process. Reject concentration specifically indicates how concentrated the salts and impurities are in the brine stream that has been separated from the purified water. This parameter is important because it signifies the effectiveness of RO plant in removing contaminants. A lower brine salinity or reject concentration indicates that the RO system is effectively removing more salts and impurities from the feedwater, resulting high quality of purified water.



To understand the value of brine salinity, we must calculate the concentration factor of RO. Concentration factor is ratio of feed water flow that enters the RO system to the volume of concentrated brine that is generated as wastewater. Following is the equation to calculate the reject concentration.

Concentration factor (CF) = $\frac{Qf}{Qb}$ .... (3)
Reject concentration (Kb) = CF × Kf .... (4)
Feed flow (Qf) = 283 LPM
Brine flow (Qb) = 184 LPM
Feed salnity (Kf) = 43,700 µS/cm
Reject concentration (Kb) = 1.53 × 43,700
= 67,212 µS/cm

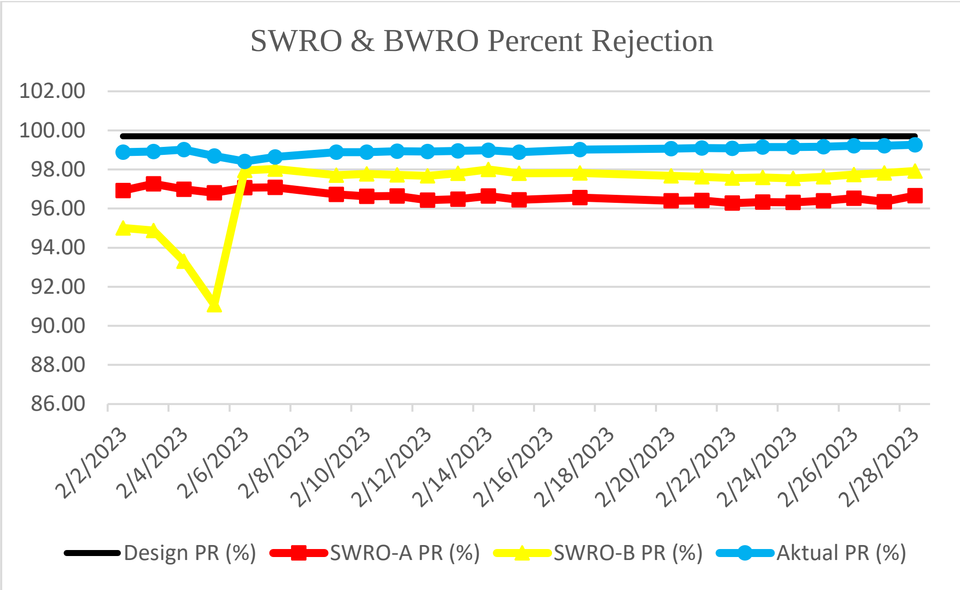
With salinity 38,500 - seawater 45,080µS/cm, reject concentration for SWRO is 60,355 - 73,013 µS/cm. It's important to note that managing the brine stream is a crucial aspect of RO plant, as the concentrated wastewater needs to be properly disposed or treated to prevent environmental impacts. High brine salinity can also indicate inefficiencies of RO process, which may require adjustments in operating conditions to optimize the systems performance. For optimization of RO plant, rejection from BWRO being used for SWRO feed as the reject concentration value is 2643 – 5634 µS/cm.

3.4 Percent Rejection

Percent rejection in RO, refers to the percentage of solutes that are effectively removed from feed water as raw material by RO membrane. Result calculation of percent rejection provide important information on how effective RO membrane converting seawater into freshwater, and how effective the RO membrane removing contaminants. This figure is the result of overall system of membrane elements, not individual numbers as already explain there is 6 membrane elements inside pressure vessel element. The higher rejection percentage the better performance of membrane elements, decreasing of rejection percentage indicates a salt passage to permeate product.

Percent rejection = $\left(1 - \left(\frac{Kp}{Kf}\right)\right) \times 100$ .... (5)
Feed salinity (Kf) = 43,700 µS/cm
Permeate salinity (Kp) = 1,348 µS/cm
= $\left(1 - \left(\frac{1,348}{43,700}\right)\right) \times 100$
= 96.92%

Percent rejection is important performance metric for assessing the effectiveness of RO system in purifying water. Higher percent rejection values indicate better membrane performance and higher water quality in the permeate stream. SWRO BBRI Plant which is using Hydranautic SWC-6 MAX membrane designed to reject minimum 99.4% of contaminants from feed water salinity and BWRO which is using Hydranautic ESPA-2 LD designed to reject minimum 99.5%. Actual average percent rejection for SWRO-A is 96.63%, SWRO-B is 97.03% and BWRO-B is 98.98%.



During RO plant operation, certain factor requires special attention. One of factors is called "concentration polarization factor" which causes a series of phenomena that affect RO membranes directly and, so, the quality of the product water and the energy consumption of the process. The concentration polarization occurs when, as feed water flows through the RO system, salts are retained by the semipermeable membrane and form a concentrated layer on its surface. The concentration at this point gradually increases because as the water flow continues to pass through the membranes, salts continue to accumulate, causing an even higher concentration than the inlet concentration. This phenomenon limits mass transfer in the process, causing an increase in; operating pressure, energy consumption, and scaling formation. It also decreases the quality and flux of the permeate.

3.5 Specific Energy Consumption

With soaring energy prices globally, the cost of producing clean water is also increasing worldwide. The use of renewable energy sources is an ideal choice, besides that renewable energy also helps reduce carbon emissions. However, the commercialization of desalination processes based on renewable energy is still far from expectations, therefore, no doubt, the focus that everyone needs to do is to reduce energy consumption or increase productivity per unit of energy use.

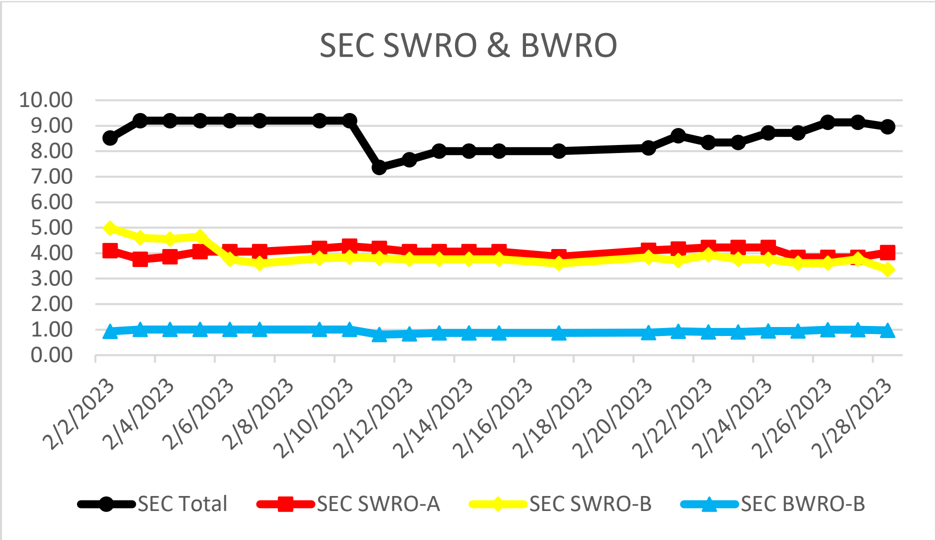
SEC is one of the key factors in desalination plant, reducing production costs will contribute to operational effectiveness in supplying clean water for human basic and industrial purposes. Moreover, reducing SEC means reducing gas combustion processes (in gas-fired power plants) which contributes to hazardous environmental emissions like CO^2 and affects environmental conservation from greenhouse effects. SEC refers to the amount of energy required to produce a certain amount of fresh water through the desalination process. In other words, SEC measures the energy efficiency of the desalination plant in converting saltwater into purified water. Mathematically, SEC is calculated as follows:

$$SEC = \frac{W}{Qp} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

W = Energy consumed (kWh)

Qp = Produced fresh water (m^3)

In SWRO desalination, the energy recovery system plays a very crucial role, due to the highest energy consumption in the conversion process and the key to restoring efficiency. Therefore, in energy recovery systems, Recovery Rate and Energy Consumption are key factors in designing SWRO. Lower SEC values indicates higher energy efficiency overall RO Plant. Lowest SWRO SEC is 3.5kW/m^3/h, with average SEC for SWRO-A is 4.05 kW/m^3/h and SWRO-B is 3.89 kW/m^3/h and BWRO-B 0.94 kW/m^3/h.



4. Conclusion

The performance analysis of desalination using RO technology critically assesses membrane effectiveness and electrical power consumption. BBRI's RO desalination plants undergo comprehensive performance evaluation, which encompasses recovery rate, membrane average flux, reject concentration, percent rejection, and SEC. The performance of these RO plants significantly influences operational efficiency, membrane durability, environmental impact, and overall energy usage.

Operating with a seawater salinity range of 38,500 - 45,080 µS/cm, SWRO with a design capacity of 210m^3/h and BWRO at 178m^3/h utilize Hydranautic SWC-6 MAX and ESPA-2 LD spiral-wound membranes. The average recovery rates for SWRO-A and SWRO-B are 35.89% and 37.02%, respectively, whereas BWRO achieves 60.12%. The average membrane flux for SWRO-A is 12.44 LPM^2/H, SWRO-B is 13.33 LPM^2/H, and BWRO-B is 29.36 LPM^2/H. The percent rejection rates are notably high, with SWRO-A at 96.63%, SWRO-B at 97.03%, and BWRO-B at 98.98%. The lowest SWRO SEC recorded is 3.5 kWh/m3 with average SEC for SWRO-A is 4.05 kW/m^3/h and SWRO-B is 3.89 kW/m^3/h and BWRO-B 0.94 kW/m^3/h.

Reject concentrations from SWRO range between 60,355 - 73,013 µS/cm, and BWRO produces reject with concentrations of 2,643 – 5,634 µS/cm, which is then fed back for SWRO feed. Scaling and fouling emerge as the primary potential causes of decreased performance in the RO desalination plant. Thus, a continuous regimen of performance analysis, equipment optimization, and scheduled chemical cleaning is indispensable for achieving peak performance in the RO desalination plant.

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