Characterization of Reverse Osmosis Reject Wastewater Generated from Sulaibiya Wastewater Treatment Plant

Mishari Khajah*, Mohd Elmuntasir Ahmed, and Abdullah Al-Matouq

***Abstract*—Sulaibiya Wastewater Treatment Plant (Kuwait) is considered as one of the largest wastewater treatment plants that use Reverse Osmosis (RO) membranes in their processes to reclaim water from municipal wastewaters for indirect potable water reuse. This result in considerable wastewater treatment brine which needs to be further investigated before discharge. Samples were collected on daily basis from the RO reject wastewater (brine wastewater) for one month and analyzed in situ and in the laboratory. The results obtained showed that the brine wastewater met the requirements of the Kuwait Environment Public Authority with the exception of biochemical oxygen demand, total dissolved solids, and total phosphate. In Kuwait, the brine wastewater is either used for deep-well injection or is discharged to the seawater. Based on the monitoring results, potential reuse options of wastewater brine include surface water discharge, sewer disposal, deep-well injection, and land application. Treatment options via evaporation ponds using membrane filters will further enhance the quality of the brine wastewater.**

***Index Terms*—Brine, potable water, reverse osmosis, Sulaibiya Wastewater Treatment Plant, wastewater treatment.**

I. Introduction

Kuwait is considered as an arid country with little rainfall (130 mm/yr) and high evaporation rates (400 mm/yr), and no natural freshwater resources except limited groundwater at Al-Rawdtain and Um Al-Aish, areas that are depleting rapidly with time [1], [2]. Most of the water resources in Kuwait are characterized as brackish water, and as a result, seawater desalination is the main source for Kuwait to meet almost all its water demands. As seawater desalination is costly, Kuwait recently adopted new alternative to meet its increasing water demands due to the rapid growth of the population. Wastewater treatment seems to be one of the sources of increasing the availability of freshwater, as other sources are diminishing. This means wastewater treatment and recirculation will play a significant role in solving the problems of freshwater shortage and environmental protection. However, the main concern with wastewater treatment reuse or recirculation is its composition (that is, nutrients (nitrogen; N, phosphorus; P), chemicals, and pathogens), which can be detrimental to human health and aquatic life and can present environmental hazards [3]-[5]. Additionally, inappropriate discharge of the wastewater would release nutrients and waterborne pathogenic microbes into the receiving water bodies or soils, which would raise environmental problems. Wastewater treatment technology is receiving a lot of attention worldwide, especially in Kuwait, which is an interesting aspect that would address the problem of the required water demands. In Kuwait, most of the treated wastewater is used for irrigation and greenery landscaping through a centralized system [6].

Kuwait has four main domestic wastewater treatment plants located in Kabd, Riqqa, Um Al-Haiman, and Sulaibiya areas. All of the wastewater treatment plants use conventional wastewater treatment (activated sludge), and more and more sophisticated processes to reach tertiary treatment level [7], except for the Sulaibiya Wastewater Treatment Plant, which adopts further advanced treatment using Ultra Filtration (UF) and Reverses Osmosis (RO) that produce potable water quality [8]. This plant was built in 2004 and is considered as one of the largest wastewater treatment plant using RO membranes in their processes to reclaim water from municipal wastewaters for indirect potable water reuse. It has treating average capacity of 375,000 m^3/d (maximum 425,000 m^3/d) [6], [9, [10], as shown in Table I [10], with a potential for future expansion of up to 600,000 m^3/d [1], [8]. An additional waste stream is generated composed of the reject of the membrane treatment or called brine wastewater, which includes contaminants such as nutrients, trace organic chemicals, effluent organic matter, and pathogens. Many of the organics that are concentrated in these brines are of considerable concern and can hinder the beneficial use of reclaimed water concentrate [11], [12].

Around 85% of the RO treated wastewater can be reused for many applications such as irrigation purposes, whereas 15% is the reject RO wastewater or brine needs further treatment before reuse or disposal [12]. Currently, there are no legally binding regulatory guidelines for brine management in Kuwait as in many countries such as the United States, Australia, and Spain. There are presently no specific government regulations or regulatory guidelines containing technical requirements, recommendations, and engineering guidance for permitting brine discharges.

TABLE I: Common Wastewater Reclamation Plants Using Membrane Technologies Worldwide

No.	Plant, country	Capacity m^3/d
1	Bedok, Singapore	32,000
2	Kranji, Singapore	40,000
3	West Basin, California, USA	50,000
4	Ulu Pandan, Singapore	170,000
5	Orange County, California, USA	270,000
6	Sulaibiya, Kuwait	425,000

This paper studies the characteristics of the reject RO wastewater or brine wastewater generated from the Sulaibiya wastewater treatment plant. The main aim is to characterize and understand the variation in the quality of the brine

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wastewater discharged from the plant.

II. Materials and Methods

A. Data Used in This Study

Samples were collected and analyzed on a daily basis from the RO reject stream for one month at the laboratories of Sulaibiya wastewater treatment plant according to the American standard methods for water and wastewater examination [13]. Electrical Conductivity (EC) and pH were determined on site using portable measuring devices. Other parameters were analyzed at the laboratory such as ammonia nitrogen (NH_3-N), chloride (Cl^-), Chemical Oxygen Demand (COD), color, free chlorine (Cl_2), nitrate (NO_3-N), nitrite (NO_2-N), Organic nitrogen (organic N), sulphates ($SO_4{}^{2}$), sulphides (S^{2-}), total coliform (T.F.), total alkalinity ($CaCO_3$), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), total phosphate, and total phosphorus.

B. Statistical Analysis

Summary statistics for September 2021 were obtained using Microsoft Excel (Table I). The data included all days of the week except Fridays. The kurtosis and skewness coefficients indicated that none of the parameters was normally distributed. Additionally, the variance and 95% confidence indicated that the data (since not normally distributed), vary daily, indicating inconsistencies in the wastewater quality or plant performance.

Notably, parameters such as COD, ammonia, and TP demonstrate high variability (Table II) and, therefore, the wastewater brine quality is inconsistent due to many factors. This indicates that in order for brine wastewater to be reused, it needs to be treated to have a reliable quality, which meets certain reuse targets.

TABLE II: Summary Statistics of Brine Quality during September 2021

Parameters	Kurtosis	Skewness	Confidence Level (95.0%)
Ammonia nitrogen (mgN/l)	4.485298876	2.081590051	0.331888796
Chloride (mg/l)	1.275032472	-0.174371149	38.08896825
Chemical oxygen demand (mg/l)	2.693769252	1.670776844	7.412730151
Color ADMI unit	-1.063383383	-0.268484431	7.574107026
Conductivity (μS/cm)	-0.053366632	0.574880154	153.599747
Free chlorine (mg/l)	10.15625	3.373241998	0.001097608
Nitrate nitrogen (mgN/l)	0.895825447	0.884642103	1.949196538
Nitrite nitrogen (mgN/l)	2.435227179	1.411424011	0.287483207
Organic nitrogen (mgN/l)	-1.084081121	-0.030815067	0.194535713
pH	1.449194361	1.229709201	0.049897916
Sulphates (mg/l)	1.117497582	0.333824852	34.54866274
Sulphides (mg/l)	0.099103863	0.369559576	0.000617658
Total coliform-presumptive (CFU/100ml)	-0.613524439	0.319904761	122.820773
Total alkalinity (mg$CaCO_3$/l)	-0.324721659	0.50903772	13.56012171
Total dissolved solids (mg/l)	-0.055721633	0.574028331	101.1139258
Total suspended solids (mg/l)	12.44915271	3.600459903	0.02888864
Total phosphate (mgPO_4/l)	-0.814822664	0.558870829	2.951687634
Total phosphorus (mgP/l)	-0.819187046	0.558872051	0.962597711

III. Results and Discussion

Brine is generally highly concentrated saline water, which contains valuable contaminants such as nutrients, heavy metals, organic matters, etc. [14]. These contaminants are of critical concern either to treat or recover depending on the concentrations and the purpose of the reuse. The characteristics of the brine vary due to the feed water sources and different treatment processes. Table III shows the characteristics of the brine from the Sulaibiya wastewater treatment plant and the maximum limits for Kuwait Environment Public Authority (KEPA) for water discharge into the Kuwait Sea and water used for irrigation.

The average conductivity of Sulaibiya`s brine wastewater was 5.13 ms/cm, which is similar to that in previous studies (reported values 4.45, 5.0, 5.0 and 4.11 ms/cm) [15]-[18], which is due to high salt content [19] and can harm the aquatic life, irrigation activities and damage the ecosystem [20]. The average chloride was 1041.23 mg/l; the high concentration is due to the use of chlorination to disinfect the water, which reduces the bacteria and viruses present before it reaches RO membrane advanced treatment. The range of chloride was between 791 and 1250 mg/l, which is higher than that of other studies (reported values 592.9, 684, and 596 mg/l) [21]-[23], whereas there were other studies that have more chloride concentrations (2811, 5200, and 1627 mg/l) [24]-[26]. Chloride above 600 mg/l could effects on human beings such as dehydration hypertension and diarrheal symptoms [27]. With regard to COD, the average was 84.77 mg/l. Similar studies have reported this range of concentrations (reported values 60, 67, and 77 mg/l) [28]-[30], this is considered as a low organic matter due to the four treatment processes (primary, secondary, tertiary, and RO membrane). On the other hand, there were several studies where COD concentrations did not exceed 200 mg/l: 158, 147, 150, and 120 mg/l [21], [31], [32]. The variation of the organic matter is due to many factors such as properties of the secondary effluents, operating conditions, produced water quality, the type of pretreatment and membrane selection [14]. As for nitrate concentrations, they ranged between 18.45 and 38.4 mg/l, which is quite high concentration due to partial conversion of the ammonium to nitrate [33], which needs serious treatment to prevent algae blooming and eutrophication phenomena [34]. The average sulphate concentrations were 690.85 mg/l less than that reported by previous studies (1584, 1437, and 1240 mg/l) [15], [24], [35]. This range is due to different wastewater sources and treatment processes. Sulphate above of 400 mg/l could effects on human beings such as dehydration hypertension and diarrheal symptoms [27]. Moreover, the average TDS concentrations were 3376.12 mg/l less than that reported by other studies (13980, 16600, and 14745 mg/l) [32], [35], [36]. This is due to different treatment processes and the growth of the microorganisms could be inhibited with high TDS concentrations [37]. In addition, total coliform and phosphate were quite low and would not have a significant impact on the environment.

TABLE III: CHARACTERISTICS OF THE RO REJECT WASTEWATER (BRINE) OF THE SULAIBIYA WASTEWATER TREATMENT PLANT WITH MAXIMUM LIMITS FOR WATER DISCHARGED INTO THE KUWAIT SEA AND WATER USED FOR IRRIGATION

Parameters	Minimum	Maximum	Average	Standard deviation	CV%	Maximum Limit for KEPA discharged into the Kuwait sea	Maximum Limit for KEPA water used for irrigation
pH	7.4	7.9	7.56	0.12	1.60	6-9	6.5-8.5
Conductivity (µS/cm)	4590	5960	5130.77	372.90	7.27	N/A	N/A
NH_3-N (mgN/l)	1.86	5.3	2.61	0.81	30.88	3	15
Cl^- (mg/l)	791	1250	1041.23	92.47	8.88	-	-
COD (mg/l)	58	138	84.77	18.0	21.23	200	100
Color (ADMIunit)	106	170	141.96	18.39	12.95	-	-
Cl_2 (mg/l)	0.03	0.04	0.032	0.004	12.50	0.2	0.5-1
NO_3-N (mg/l)	18.45	38.4	25.30	4.73	18.71	N/A	N/A
NO_2-N (mg/l)	1.5	4.6	2.38	0.70	29.30	N/A	N/A
Organic N (mg/l)	0.34	1.66	1.04	0.41	38.88	-	-
SO_4^{2-} (mg/l)	510	916	690.85	83.87	12.14	N/A	N/A
$S2^-$ (mg/l)	0	0.006	0.002	0.001	60.92	1	0.1
T.F. (CFU/100ml)	22	970	437.95	263.32	60.12	-	-
$CaCO_3$ (mgCaCO3/l)	334	466	393.85	32.92	8.36	-	-
TDS (mg/l)	3020	3922	3376.12	245.48	7.27	No more than 5% of the total TDS	1500
TSS (mg/l)	1.6	1.7	1.65	0.05	3.03	10	15
Total phosphate (mg/l)	6.2	30	14.64	7.17	48.95	1	30
Total phosphorus (mg/l)	2.02	9.77	4.77	2.34	48.95	-	-

Biochemical Oxygen Demand (BOD) is approximately and half of COD, the maximum limit for KEPA to discharge into the Sea and irrigation use (30 mg/l and 20 mg/l, respectively). However, most of organic constituents are slowly biodegradable in the effluent secondary stage [14]. Even though the average of the COD of the Sulaibiya`s brine wastewater is 84.77 mg/l, which is within the maximum limit for KEPA for discharge into the Sea and irrigation use, the BOD does not meet the maximum limits of KEPA standards. With regard to TDS, the average is 3376.12 mg/l, which is above the maximum limit of KEPA for both discharge into the Sea (no more than 5% of the total TDS of the seawater, which is 30,000–40,000 mg/l) and irrigation use (1500 mg/l). Moreover, the average of total phosphate is 14.64 mg/l, which is above the maximum limits for KEPA discharged into the Sea (1 mg/l) and within the irrigation use limits (30 mg/l). However, phosphate depends on the pH of the feed solutions [38]. Therefore, Sulaibiya`s brine wastewater should be treated for these parameters (BOD, TDS, and total phosphate) to be discharged into the sea or used for irrigation.

Presently, several brine wastewater disposal options including deep well injection, surface water discharge, and evaporation ponds have been used. However, these processes are limited by high capital cost and limited applications [39]. Currently, membrane-based technologies appear to be cost-effective treatment methods for managing brine concentrate as they can treat and remove the contaminants from the brine wastewater [40]. In Kuwait, the Kuwait Oil Company (KOC) uses the brine to enhance their oil recovery.

More potential technologies to treat the brine wastewater worldwide include forward-feed evaporator (FF-MED) for brine concentration, and Eutectic Freeze Crystallisation (EFC) with ion exchange membranes (CrIEM) for brine crystallisation [41]. In addition, RO and nanofiltration have been used to treat brine and recover valuable components such as magnesium and calcium salts [42].

IV. CONCLUSION

Data on Sulaibiya's brine wastewater quality (September 2021) were statistically analyzed and compared to Kuwait's wastewater reuse guidelines. The objectives were to determine suitability for reuse and need for treatment.

- The brine wastewater does not meet Kuwait's guidelines for reuse for both the water discharge into the Sea and the water use for irrigation with respect to BOD, TDS, and total phosphate.

- To ensure reliability of brine quality, a treatment is needed since the fluctuations in its quality are high.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Mishari Khajah is the main writer of the paper, Mohd Elmuntasir Ahmed and Abdullah Al-Matouq contributed to the data analysis; all authors had approved the final version.

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