Performance Evaluation of Commercial Package Systems Used in Kuwait for on-Site Treatment and Reuse of Domestic Wastewater

H. Abdullah*, A. Abusam, A. Mydlarczyk, A. Al-Dhafeeri, F. Al-Ajeel, A. Ali, M. Al-Jomaa, and R. Al-Yaseen

***Abstract*—Kuwait's wastewater management scheme consists of a huge centralized sewerage system that transports all wastewater generated for treatment at central municipal plants for wastewater treatment. However, there are a few remote sites that are still not connected to the public sewerage system. In such sites, on-site systems such as conventional septic tank or package systems are commonly used. This study assessed the performance of two package systems used in Kuwait for on-site wastewater treatment and reuse. Wastewater samples were collected weekly for five months from influent and effluent streams of two package systems located at Ahmedi and Kadhmah areas of Kuwait. Comparison of the means of the laboratory results to the guidelines of Kuwait Public Authority for Environment (KEPA) indicated that the effluents of the two systems are suitable to be reused as irrigation water. However, results obtained also showed that performances of both units were highly fluctuating.**

***Index Terms*—Wastewater, treatment, reuse, onsite systems, package systems.**

I. INTRODUCTION

Kuwait's wastewater management scheme consists of a huge sewerage network that collects and transports almost all wastewater generated in the country to four main municipal wastewater treatment plants (WWTPs) located at Kabd, Riqqa, Sulaibiya, and Umm-Al-Haiman. Although the sewerage network covers almost entire Kuwait, there are some spots in Kuwait City that are not connected to the public sewer [1]. Moreover, some of the remote sites are also not connected to the sewerage system. In such situation, the only option is to use an on-site wastewater treatment system.

Nowadays, a wide range of wastewater treatment technologies are used worldwide for the on-site management of wastewater. Examples of these technologies are package aerobic on-site systems [2], [3], package anaerobic on-site systems [4], package membrane bioreactor (MBR) on-site systems [5], and package hybrid anaerobic-aerobic on-site systems [6]. However, the package systems that are widely sold in Kuwait's market are often small and compact variants of the activated sludge process. They are usually sold in different designs and configurations.

The on-site wastewater treatment systems used in Kuwait can be categorized as (a) septic tank system, and (b) cesspool (joorah) system or activated sludge package system. The package systems sold in Kuwait are either made locally or imported. These package systems are often claimed to produce effluent suitable for agricultural irrigation uses. However, there is no adequate information about the designs and the performances of the package systems under Kuwait's conditions. To obtain reliable information about the performance of these systems, the Kuwait Institute for Scientific Research (KISR) has recently initiated a large project that aims to appraise and assess the performance of these package systems. This paper presents the outcomes of the first part of this project, which studied the performance of a package system called zero-waste.

The zero-waste is a small, automated treatment unit that can be easily placed outside any household or business. It applies a unique method of variable aeration and recirculation of sludge to treat efficiently domestic and household waste, with minimal by-products (sludge and smells). As shown in Fig. 1, this is an aerobic system that treats up to tertiary level, using UV disinfection.

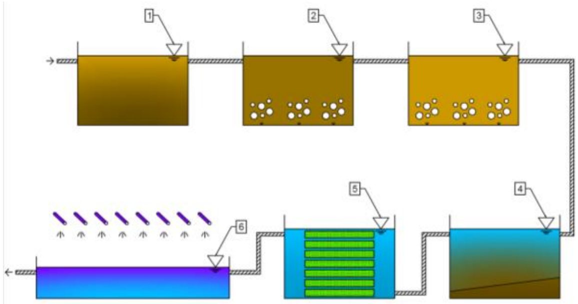

Fig. 1. Zero-waste wastewater treatment on-site unit process: 1) inlet tanks, 2) aeration chamber 1, 3) aeration chamber 2, 4) secondary settling tank, 5) up-flow mesh filtration, and 6) UV light disinfection.

II. MATERIAL AND METHODS

The study monitored the performance of two zero-waste units, one located in Ahmedi area and the other, in Kadhmah area. Influent and effluent water samples were collected weekly from the two units for five months. For the collected samples, temperature (T), pH, Electrical Conductivity (EC), and Dissolved Oxygen (DO) were first measured in situ. Then the samples were put in an icebox (4 ^{o}C) and transported to KISR's laboratories at Sulaibiya Research Plant (SRP) for further analysis.

At SRP, the values of routine wastewater quality parameters (TSS, BOD, TN, etc.), biological parameters (total coliform, fecal coliform, and salmonella spp.), and concentrations of 14 heavy metals (Al, Ar, B, Cd, Co, Cr, Cu, F, Fe, Li, Mg, Mn, Ni, and Zn) were determined, according to

Manuscript received May 27, 2022; revised June 20, 2022; accepted June 22, 2022.

H. Abdullah, A. Abusam, A. Mydlarczyk, A. Al-Dhafeeri, F. Al-Ajeel, A. Ali, M. Al-Jomaa, and R. Al-Yaseen are with the Water Research Center, Kuwait Institute for Scientific Research, P.O. Box 24885, 13109 Safat, Kuwait.

*Correspondence: hsafar@kisr.edu.kw

doi: 10.18178/ijesd.2023.14.1.1410

the standard methods for analyzing water and wastewater [7].

The two systems were found to be treating raw wastewater of medium strength (BOD5 about 200 mg/l), with slightly high nutrient concentrations. Concentrations of total nitrogen (TN) in influent stream ranged between 33 and 131 mg/l for Ahmedi unit and between 16 and 109 mg/l for Kadhmah unit. The ranges of total phosphorus concentrations were 12 to 62 and 26 to 31 mg/l at the inflow of Ahmedi and Kadhmah systems, respectively.

The suitability of these systems for use in Kuwait for the on-site production of treatment wastewater, which can be reused as irrigation water, was decided after comparing the qualities of the effluents to KEPA standards [8].

III. Results and Discussion

As shown in Fig. 2, the quality of raw wastewater treated at Ahmedi and Kadhmah units can be categorized on average as that of medium strength domestic wastewater [9]. However, there were days when the influent concentrations deviated highly from the average values of medium strength domestic wastewater (Fig. 3).

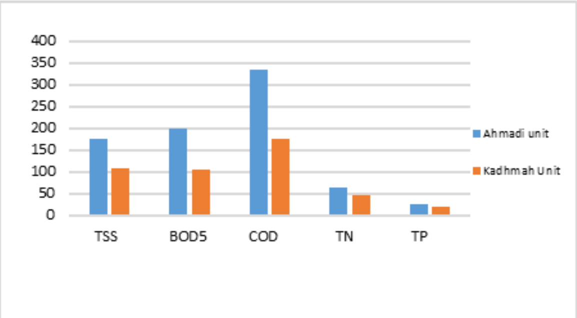

Fig. 2. The average quality of raw wastewater treated at Ahmedi and Kadhmah units.

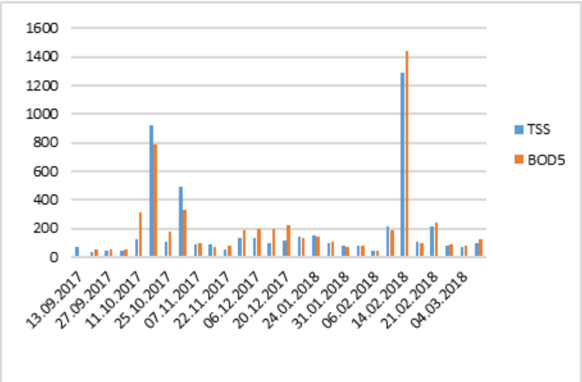

Fig 3. Quality of Ahmedi's weekly inflow wastewater.

Table I and Table II compare the average quality of the influents and effluents of Ahmedi and Khadmah units to the KEPA standards [8]. Even though the systems occasionally treated high strength wastewater, generally the quality of the effluents was found to meet all KEPA criteria, except for that of the pH values. In fact, the pH values were most of the time acidic and lesser than the range specified by the KEPA standards (6.5 to 8.5). Further, the concentrations of TSS, BOD_5, COD, NH_3-N, TKN, and TP exceeded the KEPA standards occasionally. Also, the concentrations of TDS, NH_3-N, TKN, NO_3-N, TN, HCO_3, and TP in the effluents and influents were found to correlate. These results, as expected, indicated that the two units were sensitive to the fluctuations in the influent loads of solids, organic and nutrients.

TABLE I: Comparison of the Influents of Ahmedi and Kadhmah Units to KEPA Standards

Parameter	Ahmedi Unit		Kadhmah Unit		KEPA Standards
	Mean	Range	Mean	Range	
pH	6.7	5.8–7.3	6.8	6.1–8.5	6.5-8.5
TSS (mg/l)	176.6	38–1292	107	7–1470	15
TDS (mg/l)	396.3	244–532	285	141–378	1500
VSS (mg/l)	156.1	35–1076	86	7–1048	---
BOD_5 (mg/l)	200.1	47.5–1440	105	16–1017	20
COD (mg/l)	334.6	73–2380	174	27–1650	100
O&G (mg/l)	5.4	2–12.5	4	0–14	5
NH_4-N (mg/l)	35.8	11.2–84.7	26	0.2–56	15
TKN (mg/l)	55.7	22–120.4	37	15–106	35
NO_3-N (mg/l)	7.7	0–29.7	8	0.5–36	---
NO_2-N (mg/l)	0.2	0–0.5	0.1	0–0.5	---
TN (mg/l)	63	33–131	45	16–109	---
TP (mg/l)	26.2	12.2–61.5	19	2.6–31	30
BOD/COD ratio	0.6	0.5–0.7	0.6	0.5–0.6	30

Note: KEPA: Kuwait Environmental Public Authority, STD: Standard Deviation, pH: Hydrogen Ion, TSS: Total Suspended Solids, TDS: Total Dissolved Solids, VSS: Volatile Suspended Solids, BOD_5: Biochemical Oxygen Demand, COD: Chemical Oxygen Demand, O&G: Oil and Grease, TKN: Total Concentration of Organic Nitrogen and Ammonia, TN: Total Nitrogen, TP: Total Phosphorous, mg/L: Milligram per liter.

TABLE II: Comparison of the Effluents of Ahmedi and Kadhmah Units to KEPA Standards

Parameter	Ahmedi Unit		Kadhmah Unit		KEPA Standards
	Mean	Range	Mean	Range	
pH	6.0	4.5–7.2	5.2	3.1–6.9	6.5-8.5
TSS (mg/l)	7.2	1–44	17	3–65	15
TDS (mg/l)	382.1	264–476	245	134–350	1500
VSS (mg/l)	6.8	0.9–42	16	2–62	---
BOD_5 (mg/l)	16.4	3.1–59.4	27	8–69	20
COD (mg/l)	27.7	5–105	45	14–116	100
O&G (mg/l)	0	0	0	0–0	5
NH_4-N (mg/l)	14.6	0–76.9	7	0.4–18	15
TKN (mg/l)	24.8	7.9–79.6	21	6–39	35
NO_3-N (mg/l)	10.9	1.4–45.1	9	2–35	---
NO_2-N (mg/l)	0.3	0–0.5	0.1	0.0–0.5	---
TN (mg/l)	35.8	12–88	30	11–56	---
TP (mg/l)	21.7	10–34.4	16	6–28	30
Al (mg/l)	0.0353	0.0063-0.1974	0.0531	0.0046–0.1441	30
As (mg/l)	0.0038	0.0002–0.0202	0.0020	0.0003–0.0066	5
Cd (mg/l)	0.0006	0.0001–0.0013	0.0008	0.0002–0.0021	0.1
Co(mg/l)	0.0019	0.0003–0.0069	0.0022	0.0006–0.0056	0.01
Cr (mg/l)	0.0008	0.0003–0.0020	0.0010	0.0004–0.0021	0.2
Cu (mg/l)	0.0049	0.0004–0.5220	0.0098	0.0035–0.0263	0.15
Mn (mg/l)	0.0034	0.0041–0.1831	0.0261	0.0028–0.0802	0.2
Ni (mg/l)	0.0038	0.0004–0.0356	0.0036	0.0008–0.0099	0.2
Zn (mg/l)	0.0444	0.0019–0.2604	0.0821	0.0007–0.2402	0.2

B (mg/l)	0.2610	0.0345–2.042	0.0743	0.0125–0.3217	2.0
Fe (mg/l)	0.1454	0.0135–0.5956	0.2524	0.0366–0.5907	2.0
Li (mg/l)	0.0118	0.0017–0.0793	0.0042	0.0015–0.0137	5.0
Ca (mg/l)	28.1	16–37.8	25.64	6.59–42-.04	---
K (mg/l)	11.72	3–18.3	9.80	3.0–18.3	---
Mg (mg/l)	4.6	1.2–6.6	3.96	1.15–6.59	---
Na (mg/l)	38.1	8.5–53.3	32.11	8.51–53.25	---
Total Coliform	1167	1 to >2419	981.8	1–2419.6	---
Fecal Coliform (CFU/100	241	<30 to >300	30.33	5–61	20
Salmonella (CFU/100	97	40–144	13	8–18	--

Note: KEPA: Kuwait Environmental Public Authority, STD: Standard Deviation, pH: Hydrogen Ion, TSS: Total Suspended Solids, TDS: Total Dissolved Solids, VSS: Volatile Suspended Solids, BOD_5: Biochemical Oxygen Demand, COD: Chemical Oxygen Demand, O&G: Oil and Grease, TKN: Total Concentration of Organic Nitrogen and Ammonia, TN: Total Nitrogen, TP: Total Phosphorous, MPN: Most probable number, CFU: Colony forming unit, mg/L: Milligram per liter. Kuwait Environmental Public Authority [8], Kuwait Al-Youm newspaper, Issue 533, Year 2017

According to Metcalf and Eddy [9], the average TSS concentration of medium strength raw wastewater is 210 mg/l. Fig. 4 shows clearly that TSS values had reached almost 1000 mg/l, or even more, on two sampling days (18/10/2017 and 11/2/2018). In fact, the TSS values for these two days were about 5 times the expected concentration (210 mg/l). The reason for this increase could be dumping wastewater with high solid contents into the system.

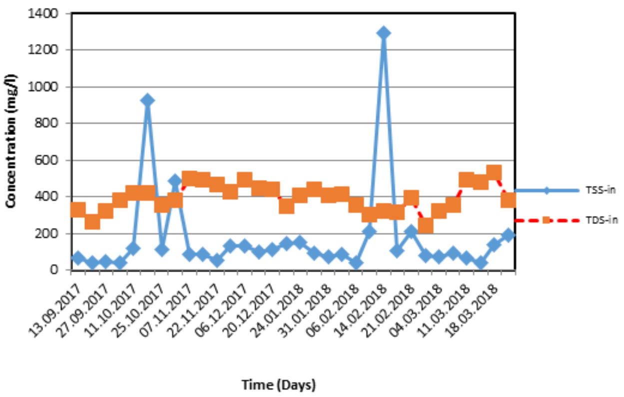

Fig. 4. TSS and TDS values of raw wastewater at Ahmedi unit.

The influent of the system located at Kadhmah can also be categorized as medium strength wastewater (Table II). However, the concentrations of the solids (Fig. 5) and organics (Fig. 6) were highly fluctuating, as indicated by the STD values being higher than the mean values.

As shown in Fig. 7, the organic loading was also very high on the same two sampling days as mentioned for TSS. The maximum values of both BOD_5 and COD of the influent sample collected on these 2 days were 1440 and 2380 mg/l, respectively. This high organics concentration (more than five times that for medium strength wastewater) was inexplicable. Nonetheless, the BOD/COD ratio averaged to 0.5 was obtained for all sampling days. This indicates that the organics in the influent were easily degradable by bacteria. The BOD/COD ratio of biodegradable organics ranges from 0.3 to 0.9 [9].

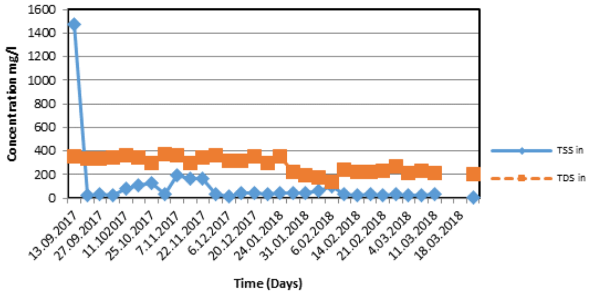

Fig. 5. Solids loading of Kadhmah unit during sampling days.

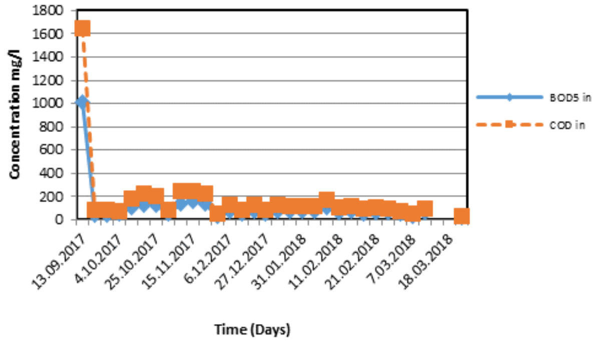

Fig. 6. Organics loading of Kadhmah unit during sampling days.

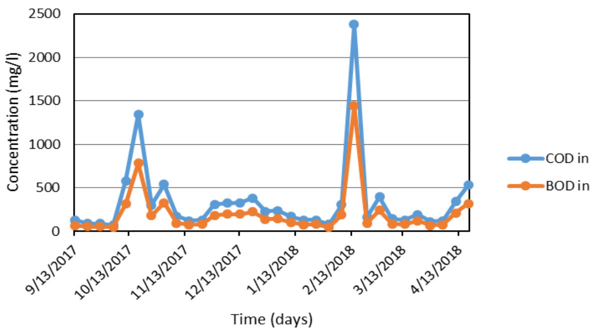

Fig. 7. BOD_5 and COD values of raw wastewater at Ahmedi unit.

Furthermore, the concentrations of the nutrients (TN and TP) of Kadhmah treatment unit were relatively lower than those of the influent in the unit located at Ahmedi (Table I). However, compared to the concentrations of both TN and TP in the Ahmadi unit (Fig. 8), those in the Kadhmah unit were fluctuating at higher rates (Fig. 9). Furthermore, for the Ahmedi system, the organics were also easily biodegradable. The BOD/COD ratio ranged from 0.5 to 0.6 (Table II).

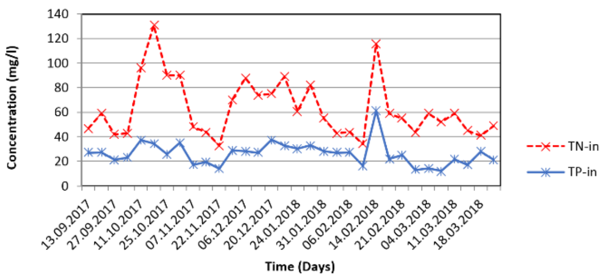

Fig. 8. Nutrients loading during sampling days of Ahmedi unit.

Average concentrations of TN and TP in medium strength raw domestic wastewater are usually 40 and 7 mg/l, respectively [9]. However, the concentrations of TN and TP in the influent samples collected from the zero-waste unit located at Ahmedi were always higher than these values. On average, the mean concentrations of TN and TP were 63 and

26 mg/l, respectively (Table I). Further, TN concentrations were fluctuating highly between 33 and 131 mg/l (Fig. 8).

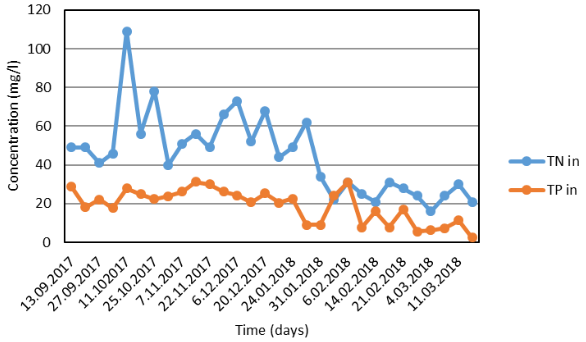

Fig. 9. Nutrients loading during sampling days of Kadhmah unit.

Although the mean values of NH_4-N effluent concentrations (Table I) of both Ahmedi and Kadhmah units satisfied the KEPA requirements (Table I), the concentrations of NO_3-N in the effluent were high and in many instances greater than those of the influent concentrations. This simply means that the denitrification process (conversion of NO_3-N to nitrogen gas (N_2)) was poor. Poor denitrification was also evident from the lower alkalinity of the effluents (Fig. 10) compared to the influents. In contrast, efficient denitrification process usually adds alkalinity to treated wastewater [9]. The low alkalinity of the effluent also explains the low pH values obtained for the effluents. Poor denitrification was probably due to the high concentration of DO in the anoxic zone. However, this needs to be investigated further.

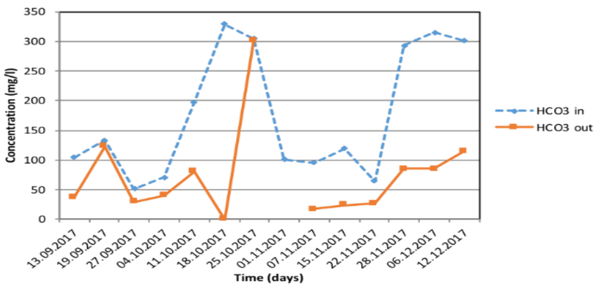

Fig. 10. Influent and effluent bicarbonate (HCO_3) alkalinity values for Ahmedi unit.

As the zero-waste system is not designed for phosphorus removal, the concentration of phosphorus in the effluent streams were found to be almost equal to that of influent streams. In fact, phosphorus concentration in the effluent was slightly higher than that in the influent (Fig. 11 and Fig. 12). This increase can be attributed to the death and lysis of bacteria and consequent release of some phosphorus from dead bacteria into wastewater. However, the slight decrease of phosphorus found on some days can be ascribed to its use by bacteria for bodybuilding. Phosphorus is an essential nutrient for growth of bacteria.

With respect to the bacteriological qualities of the treated wastewater, the effluents of both Ahmedi and Kadhmah systems generally did not meet the KEPA standards (Table I). This clearly indicates that the ultraviolet (UV) unit was ineffective in disinfecting the effluents. The reason could be the unsuitable design and/or inadequate operation of the UV unit. However, this problem also needs to be investigated thoroughly in a future study.

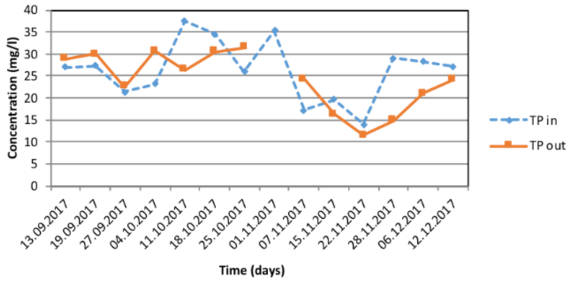

Fig. 11. Influent and effluent TP values for Ahmedi unit.

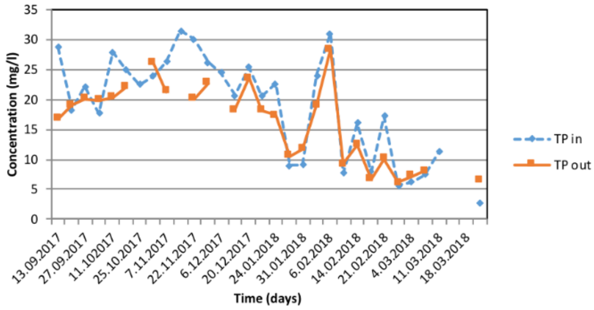

Fig. 12. Influent and effluent TP values for Kadhmah unit.

Despite treating the wastewater of Ahmedi unit, which was characterized by occasionally high loading rates, on average the effluents were found to meet all KEPA criteria, except for pH values. The pH values were most of the time acidic (4.5 to 7.2) and lesser than the range specified by the KEPA standards (6.5 to 8.5). Further, the concentrations of TSS, BOD_5, COD, NH_3-N, TKN, and TP exceeded occasionally the KEPA standards. However, the increase in the concentrations of TDS, NH_3-N, TKN, NO_3-N, TN, HCO_3, and TP were clearly correlated with the concentrations in the influent (Figs. 13-17). This indicates that the system was sensitive to fluctuations in dissolved solids and nutrients concentrations.

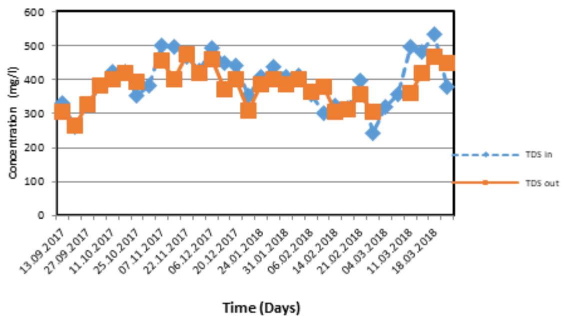

Fig. 13. Influent and effluent TDS values during sampling days of Ahmedi unit.

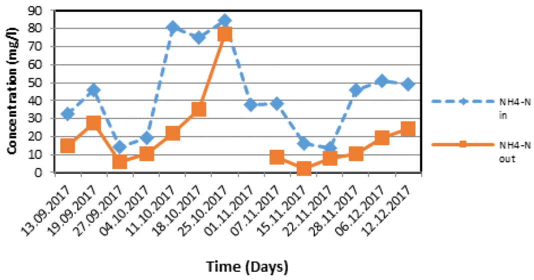

Fig. 14. Influent and effluent NH_3-N values during sampling days of Ahmedi unit.

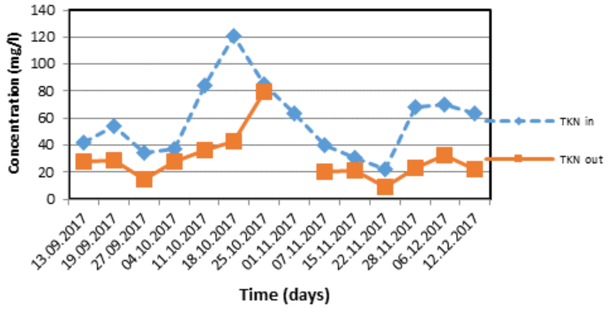

Fig. 15. Influent and effluent TKN values during sampling days of Ahmedi unit.

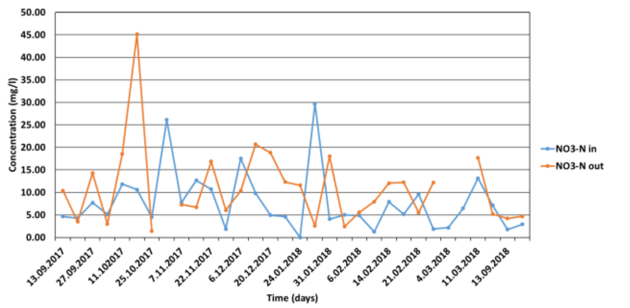

Fig. 16. Influent and effluent NO_3-N values during sampling days of Ahmedi unit.

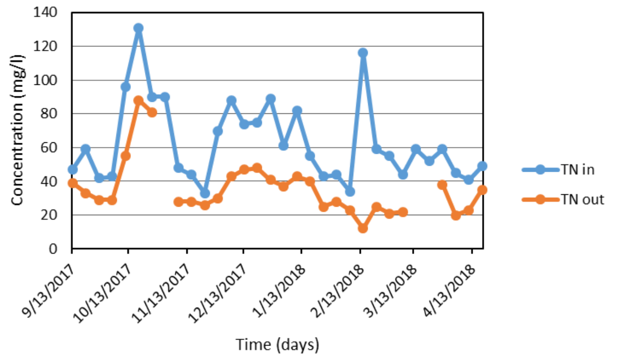

Fig. 17. Influent and effluent TN values during sampling days of Ahmedi unit.

The mean value of the effluent satisfied the KEPA requirements with respect to NH_4-N. NO_3-N concentrations were high and in many instances greater than the influent concentrations (Fig. 14 and Fig. 16). That is, there was no denitrification process (conversion of NO_3-N to nitrogen gas (N_2)). In fact, NO_3-N converted from NH_4-N (nitrification process) was added to the influent NO_3-N concentration (Fig. 16). Poor denitrification was also evident from the lower alkalinity of the effluent compared to the influent. The nitrification process usually consumes the alkalinity, whereas the denitrification process adds alkalinity [9]. In fact, the low alkalinity of the effluent explains the low pH values. Poor denitrification was probably due to the high concentration of DO in the anoxic zone.

Also, the values of effluent of the Kadhmah's unit meet all KEPA standards, except for the pH value, which was also mostly acidic and less than 6.5. The pH of the effluent of this unit ranged from 3.1 to 6.9 with an average value of 5.2.

Similar to those in the unit located at Ahmedi, the effluents of the system located in Kadhmah had also shown instances where the values of BOD_5, COD, NH_4-N, TKN, and TSS exceeded the KEPA standards. Like the Ahmedi system, the concentrations of dissolved solids and nutrients in the effluent were also found to be sensitive to corresponding concentrations in the influent (Figs. 18-20).

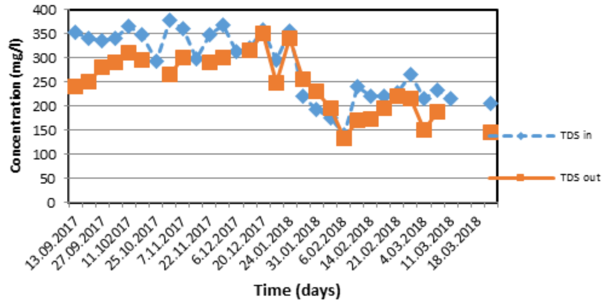

Fig. 18. Influent and effluent TDS values during sampling days of Kadhmah unit.

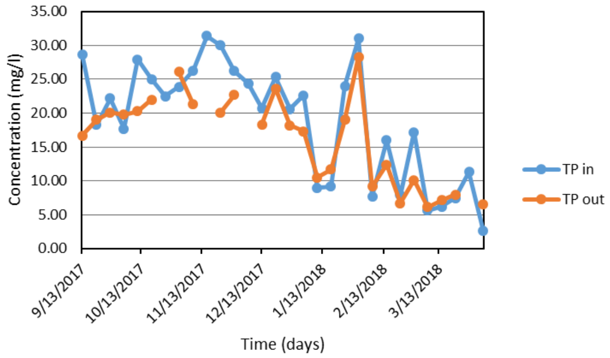

Fig. 19. Influent and effluent TP values during sampling days of Kadhmah unit.

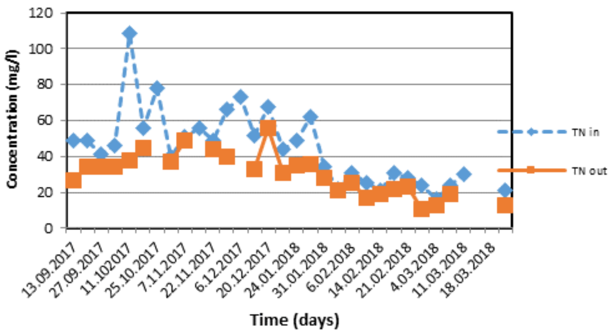

Fig. 20. Influent and effluent TN values during sampling days of Kadhmah unit.

Similar to the system located at Ahmedi, the unit at Kadhmah had shown to have efficient nitrification (conversion of NH_4-N to NO_3-N) but poor denitrification (reduction of nitrates), as shown in Fig. 21 and Fig. 22, respectively. Absence of the denitrification had probably led to low alkalinity of the effluent (Fig. 23).

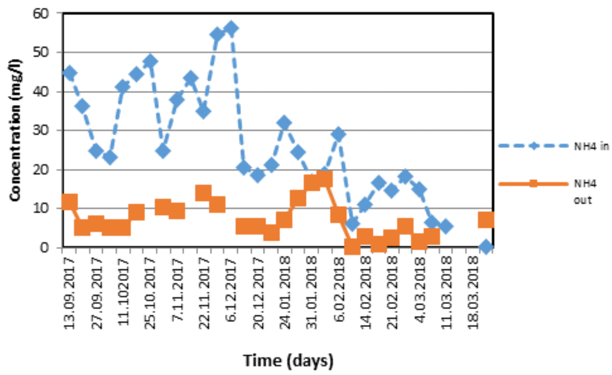

Fig. 21. Influent and effluent NH_4-N values during sampling days of Kadhmah unit.

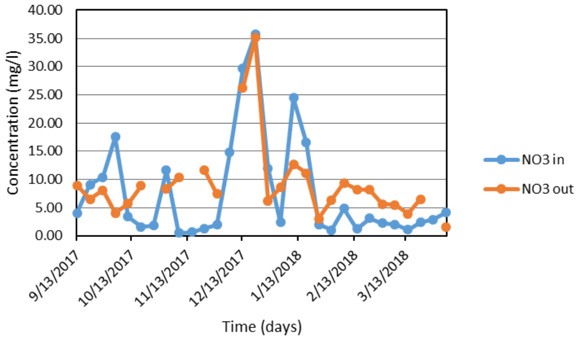

Fig. 22. Influent and effluent NO_3-N values during sampling days of Kadhmah unit.

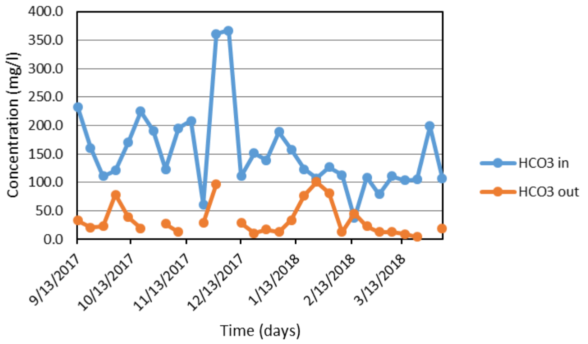

Fig. 23. Influent and effluent bicarbonate (HCO_3) values during sampling days of Kadhmah unit.

The zero-waste is not designed for enhanced phosphorus removal, as mentioned earlier; thus, phosphorus was also almost not removed at all by the system at Kadhmah (Fig. 24).

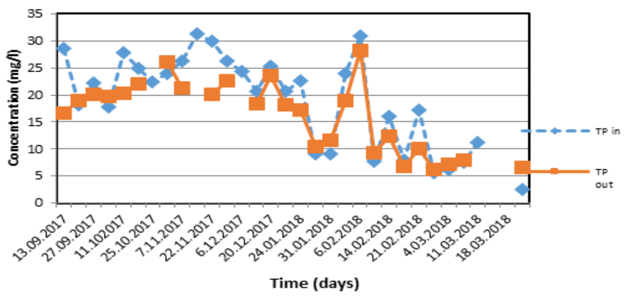

Fig. 24. Influent and effluent TP values during sampling days of Kadhmah unit.

Finally, both Ahmedi and Kadhmah units satisfied the KEPA guidelines for the concentrations of heavy metals, except for zinc, in treated wastewater. The concentrations of zinc were found in few days to be slightly higher than KEPA standard of 0.2 mg/l.

In general, the effluent treated wastewater from on-site treatment units at both Ahmedi and Kadhmah did not meet KEPA standard for irrigation usages. The influents of both Ahmedi and Kadhmah units were generally medium strength raw wastewater and amenable for biological treatment, as indicated by the average BOD/COD ratio of 0.6. However, there were sampling days on which the concentrations of the solids and organics were relatively high for domestic wastewater. Concentrations of TSS, BOD_5, and COD in a medium strength raw wastewater are expected to be about 200, 190, and 430 mg/l, respectively [9]. On some days, however, the concentrations of TSS, BOD_5, and COD were found to be 1470, 1017, and 1650 mg/l, respectively. Therefore, it can be concluded that the unit situated in Ahmedi occasionally treated a high strength wastewater that was amenable to biological treatment. In contrast, the concentrations of TSS, BOD_5, and COD of the influent stream to Kadhmah unit were within the ranges for a medium strength raw wastewater. The values of solids and organics obtained on the first day of sampling were clearly outliers.

With respect to nutrient loading, Metcalf and Eddy [9] reported that concentrations of a medium strength raw wastewater are about 25, 40, 0, 0, 40, and 7 mg/l for NH_4, TKN, NO_3, NO_2, TN, and TP, respectively. However, concentrations of the influents to both Ahmedi and Kadhmah units have occasionally exceeded these ranges. Despite the instances of high loadings, effluents of both units had broadly met the KEPA standards, except for pH, total and fecal coliform, for reuse as irrigation water.

Despite the superior removal of oil and grease, NO_3 was hardly removed due to poor denitrification, which was probably caused by high DO concentration in the anoxic zone and/or lack of sufficient alkalinity. The concentrations of NO_3 in the effluent of Ahmedi averaged to 10.9 mg/l and ranged between 1.4 and 45.1 mg/l. Similarly, that of Kadhmah unit averaged to 9 mg/l and ranged between 2 and 35 mg/l. Although NO_3 is not specified within KEPA standards, such high concentration can cause problems to human health. Concentrations of NO_3 higher than 10 mg/l have been known to cause blue baby syndrome [10]. Poor denitrification process can also be the cause of the low alkalinity concentrations observed for both Ahmedi and Kadhmah units. Usually the nitrification process consumes the alkalinity, while the denitrification process adds alkalinity [11]. In that case, external alkalinity needs to be added [12]. Proper control of the aeration pattern and confining it to the aerobic zone will definitely improve the rate of nitrogen removal [13].

Another problem with the monitored zero-waste units is the poor disinfection of bacteria, particularly, the inactivation of fecal coliform. In general, removal of bacteria from the wastewater after passing through the UV disinfection unit was poor for both systems (Ahmedi and Kadhmah units). It seems there was a design or an operational problem, or both. Therefore, a future study is required that is devoted solely to investigating the performance of such UV disinfection units of on-site treated wastewater in Kuwait. Usually, UV disinfection after such a secondary treatment removes all bacteria significantly [14].

A similarly poor performance was observed for similar package systems in Virginia, USA [14]. Main reasons for that were mechanical failure and improper maintenance [2]. For the zero-waste units studied, however, the reasons could be improper operation and maintenance. As mentioned before, the poor denitrification process results by the zero-waste units can be attributed to both improper aeration patterns and low alkalinity. Further, the improper maintenance had definitely affected all the removal processes.

However, the low or negative removal percentage of heavy metals by the zero-waste units was expected because the system is not designed for that purpose. Heavy metals are mainly removed by chemical precipitation, oxidation-reduction, filtration, ion exchange, and evaporation recovery [15]. However, the zero-waste system has not even a filtration unit to absorb heavy metals.

IV. Conclusions

Although they were treating medium strength wastewater, both Ahmedi and Kadhmah units had experienced high loading conditions of solids (TSS), organics (BOD, COD), and nutrients (TN, TP). Probably for these reasons, the effluents of these two units did not meet all KEPA standards for reuse as irrigation water. Nonetheless, they had satisfied KEPA standards for O&G concentrations (5 mg/l) and concentrations of heavy metals throughout the study period. However, they did not meet KEPA criteria with respect to pH and bacteriological qualities. Further, NO_3 concentrations were higher than 10 mg/l recommended by WHO for safe reuse of treated wastewater.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The author and the principle investigator, Dr. A. Abusam, both initiated the concept of the project and wrote this paper. Dr. A. Mydlarczyk and Mr. R. Al-Yaseen contributed in collecting data and drawing the attached plots and diagrams. Mrs. F. Al-Ajeel, Mrs. A. Ali, and Mrs. M. Al-Jomaa contributed in conducted chemical, physical and biological analysis of all collected wastewater samples. Mr. A. Al-Dhafeeri contributed in the process of field investigation and wastewater sample collection of both Ahmedi and Kahdmah locations.

Acknowledgements

I would like to take this opportunity to thank the Kuwait Institute for Scientific Research (KISR) as project funder and the Water Research Center (WRC) for their motivation and financial support to complete this project. In addition, I would like to thank KISR's management including Dr. Samira Said Omar, KISR's Director General; Dr. Muhammad Al-Rashed, WRC's Executive Director; Dr. Khaled Hadi, WRC's Director of the Operation Division; Dr. Yousef Al-Wazzan, WRC's Science and Technology Director; Dr. Adel Al-Haddad, Program Manager of Water Treatment and Reclamation Technologies (WTRT), for their persistent effort to promote KISR's image as a leading scientific organization on national, regional, and international levels.

Special thanks for my team and each member who supported the completion of this project including Dr. Abdullah Abusam, Dr. Andrzej Mydlarczyk, Mr. Rashed Al-Yaseen, Mr. Ayyad Al-Dhafeeri, Ms. Farah Al-Ajeel, Ms. Mariam Al-Jomaa, Ms. Ameena Ali, Mr. Mohammad Haider, Mr. Vinod Kumar, and Ms. Geomcy George. They provided continuously a great deal of scientific and technical support.

References

[1] A. M. Shahalam, "Bench-scale studies to improve the quality of conventional septic tank effluent," Project Report No. KISR11565 presented at Kuwait Institute for Scientific Research, Kuwait, 2013.

[2] J. Kleshinski, "Big things come in small packages," *Water Environment and Technology*, vol. 13, no. 5, pp. 64-69, 2001.

[3] S. M. Choi, Y. K. Oh, and C. H. Park, "The evaluation of applicability for development of advanced package system (BioKube) for sewage treatment," *Desalination and Water Treatment*, vol. 54, no. 13, pp. 3682-3688, 2015.

[4] M. K. Sharma, V. K. Tyagi, G. Saini, and A. A. Kazmi, "On-site treatment of source separated domestic wastewater employing anaerobic package system," *Journal of Environmental Chemical Engineering*, vol. 4, no. 1, pp. 1209-1216, 2016.

[5] C. S. Tai, J. Snider-Nevin, J. Dragasevich, and J. Kempson, "Five years operation of a decentralized membrane bioreactor package plant treating domestic wastewater," *Water Practice and Technology*, vol. 9, no. 2, pp. 206-214, 2014.

[6] S. Liu, B. Wang, H. Han, and Y. Liu, "New process for alleviation of membrane fouling of modified hybrid MBR system for advanced domestic wastewater treatment," *Water Science and Technology*, vol. 58, no. 10, pp. 2059-2066, 2008.

[7] American Public Health Association (APHA). (2017). Standard Methods for examination of water and wastewater. [Online]. Available: https://secure.apha.org/imis/ItemDetail?iProductCode=978-087553-2875&CATEGORY=BK

[8] Kuwait Environmental Public Authority (KEPA), *Kuwait Al-Youm Newspaper*, Issue 1355, 2017.

[9] MetCalf and Eddy Inc., *Wastewater Engineering Treatment, Disposal, Reuse*, 3rd ed. New York: McGraw-Hill Publishing Company Ltd, 2003.

[10] Regional Center for Environmental Health Activities (CEHA), *The World Health Organization, A Compendium for Wastewater Reuse in the Eastern Mediterranean*, WHO, 2006.

[11] E. C. Raper, R. Fisher, D. R. Anderson, T. Stephenson, and A. Soares, "Alkalinity and external carbon requirements for denitrification-nitrification of coke wastewater," *Environmental Technology*, vol. 39, no. 17, pp. 2266-2277, 2018.

[12] M. K. Perera, J. Englehardt, G. Tchobanoglous, and R. Shamskhorzani, "Control of nitrification/denitrification in an onsite two-chamber intermittently aerated membrane bioreactor with alkalinity and carbon source addition: Model and experiment," *Water Research*, vol. 115, no. 5, pp. 94-110, 2017.

[13] G. Liu and J. Jianmin, "Achieving advanced nitrogen removal for small flow wastewater using a Baffled Bioreactor (BBR) with intermittent aeration," *Journal of Environmental Management*, vol. 199, no. 9, pp. 222-228, 2017.

[14] D. S. Francy *et al.*, "Comparative effectiveness of membrane bioreactors, conventional secondary treatment, and chlorine and UV disinfection to remove microorganisms from municipal wastewaters," *Water Research*, vol. 46, no. 13, pp. 4164-4178, 2012.

[15] S. Rajendran *et al.*, "A critical and recent developments on adsorption technique for removal of heavy metals from wastewater-A review," *Chemosphere*, vol. 303, article 135146, 2022.

H. Abdullah was born in Kuwait on the 20th of August, 1978. In 2016, the author received his Ph. D. in chemical engineering and analytical science from the University of Manchester, UK. The topic of the author's dissertation is related to industrial wastewater treatment using adsorption and electrochemical regeneration. In addition, the author gained his M.Phil. in 2011 in chemical engineering from Swansea University, UK. His research topic was industrial wastewater treatment by heterogeneous catalytic ozonation. He obtained his degree of bachelors in civil and environmental engineering in 2001 from West Virginia University, USA.

He has intensive experience in using HPLC including liquid analysis for organic and inorganic micropollutants, developing different methods of usage and instrument maintenance. He has worked on surface morphology analysis using different instruments including XPS, SEM, ToF-SIMS, and AFM. He is currently working on several projects related to water and wastewater treatment technologies for reuse/recycling. He is an editorial member at *Engineering and Applied Science Journal*. He is a member in several committees including the Strategic Management Analysis Team (SMAT), Associate of Agricultural Research Institutes in the Near East and North Africa (AARINENA), and Innovation Development Program

Committee (IDPC). Currently, he is an associate research scientist at the Water Research Center of the Kuwait Institute for Scientific Research. He has published three papers in the refereed journal including "Heterogeneous Catalytic Ozonation of Diethyl Phthalate", "Treatment of Organic Matter and Sulfides from Hospital Wastewater in Kuwait" and "Effect of Electrochemical Regeneration on the Surface of a Graphite Adsorbent Loaded with an Organic Contaminant".

Dr. Abdullah has received the award of the best paper in 2019 for the conference paper "Adsorption and Electrochemical Regeneration for Industrial Wastewater Treatment".