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Application of ultrafiltration membrane-embedded activated carbon-filter in Kuwait wastewater treatment in comparison with a conventional method

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ABSTRACT

Availability of clean water especially for countries with scarce freshwater resources is of great importance. Recently, ultrafiltration water purification membrane technology has been widely investigated to overcome this problem. In this study, an ultrafiltration membrane incorporated with an activated carbon filter (UF-AC) is used to treat the municipal wastewater in Kuwait, and its efficiency and economic analysis of the method is compared with the conventional method primary (solid removal), secondary (bacterial decomposition), and tertiary (disinfection) that is currently used. The treated influent samples by UF-AC revealed high reduction percentage, for total suspended solids (TSS) (98.37%), biological oxygen demand (BOD) (91.73%), turbidity (99.85%), coliform, fecal coliform, and salmonella bacteria (99.99%). However, for conventional method were for TSS (89.13%), BOD (91.6%), and turbidity (96.88%). The results for effluent water, showed further reduction percentage. The suitability of the treated water was compared to the recommended Kuwait Environment Public Authority standard irrigation limits. The results show that the UF-AC membrane is quite similar or more effective than the conventional method in contaminants removal and the purified water can be utilized for irrigation purposes. Furthermore, based on the economical results of this study, the UF-AC unit can be economically used in the wastewater treatment plant in Kuwait.

Keywords: Activated carbon filter; Irrigation; Membrane; Ultrafiltration; Wastewater

1. Introduction

The presence of different kinds of pollutants in wastewater, along with the increased demand for freshwater due to the increase in human population have made wastewater treatment a necessity [1]. In Kuwait, there are no natural freshwater sources apart from small amounts of brackish (salty) water [2]. Hence, to satisfy the country's water demands, seawater desalination is the only effective option. On the other hand, the wastewater generated in Kuwait is different in each season and it is estimated that the amount would rise as further domestic areas are associated with the sewage system [3,4].

Recycling of wastewater can aid in maintaining sustainable development in Kuwait. The significant consumption of water for different applications such as agricultural, domestic, and industrial reasons has caused an increased demand for the reuse of treated wastewater. There is

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also a political and socioeconomic stake to provide an alternative water resource at a low cost which could contribute to reducing the water concern on the society [3].

Kuwait has four wastewater treatment plants (WWTPs) that produce reusable effluent and 600,000 m^3/d of wastewater is generated from the WWTPs. The treatment in the WWTPs undergoes three stages which are primary, secondary, and tertiary. Sixty percent of wastewater is treated using UF and reverse osmosis (RO) in Sulaibiya WWTP, which makes it the largest membrane-based water reclamation facility in the world [4]. In recent decades, ultrafiltration (UF) membrane has been successfully used to remove any particulates from wastewater [5]. Therefore, the potential of using UF method instead of or in conjunction with the conventional method for treating wastewater to meet agricultural water demands appears to be a promising solution. UF membrane has been used to either replace existing secondary (coagulation, flocculation, sedimentation) and tertiary filtration (sand filtration and chlorination) systems employed in water treatment plants or as standalone systems in isolated regions with growing populations. UF membranes function as semi-permeable barriers that allow target components to pass through, while retaining others. Ultrafiltration modules efficiently separate out microorganisms, suspended solids and other contaminants.

UF processes are currently preferred over traditional treatment methods because it does not require chemicals (aside from cleaning), it produces constant product quality regardless of feed quality, it has compact plant size, and it is capable of exceeding regulatory standards of water quality, achieving 90%–100% pathogen removal. Netherlands is another example that uses UF technology and has been successfully operating since 1999 [6]. The availability of safe and clean water decreases daily, and its utility is even expected to increase in upcoming decades.

Ultrafiltration is proven to be a competitive treatment and a novel method compared with conventional ones [7]. Combination of coagulation/UF can also be considered for surface waters containing high level of organics and to minimize membrane fouling potential. The criteria for good quality water established by safe level of physical, chemical, and biological properties of water, which have significant adverse effects on aquatic organism growth and survival. To increase the quality of water input, the use of UF will surely retain the pathogen and generate highly free pathogenic water. Ultrafiltration is a novel method of disinfection and showed reduction of indicator bacteria; fecal coliforms including E. coli (FC) and fecal enterococci (FE) [8].

The tubular ceramic UF membrane have confirmed the UF usability for separation of oily wastewaters containing a large amount of suspended solids, generated during maritime transportation [9].

Activated carbon (AC) is also identified as a very good adsorbent due to its high porosity and large surface area. It is mainly used as an efficient method to remove organic and odor compounds, reduce turbidity, solids removal, and biological stabilization [10].

AC is characterized by its high ability to absorb the gases and toxins around it. It is also used in making masks and other safety tools for firefighters and miners. It is also used to purify polluted water and wastewater for use for drinking, agriculture, and industry. It is also used to kill bacteria and remove unpleasant odors. It is now known that activated charcoal is the best and most widely used adsorbent in all fields [11].

The application of AC in conjunction with MF/UF membranes is an emerging technology for the removal of organic compounds in drinking water treatment, which incorporates the adsorption capabilities of AC and the microorganism and particle removal ability of the MF/UF membranes AC in combination with different techniques is considered as an effective method for landfill leachates treatment [10]. Hence, in this study, AC along with UF is used to increase the efficiency of contaminants removal from wastewater.

UF alone also is not very effective for removing DBPs and dissolved substances in general, and have limited capability in removing organic matter. The use of powdered activated carbon (AC) in combination with UF membrane is attracting increasing interest for the removal of organic compounds in drinking water treatment [12–14]. It was found that micropollutants, such as pharmaceutical residues, phenolic compounds, bacteria and microplastic particles, present in wastewater, could be removed by including a novel ultrafiltration (UF), followed by a biofilter using granulated active carbon (GAC) as filter material below the detection limits [13]. Recent studies showed that using PAC with polymeric MF and nano membranes to treat polluted water reduces the fouling rate by removing natural organic matter (NOM), compared with the system with no adsorbent [15].

Recently, nanofiltration (NF) membrane techniques have been used successfully for wastewater treatment. NF membrane can separate the low molecular weight pollutants and reject heavy metals. The combination of NF with other techniques results in improving water quality [16]. Activated carbon-bentonite absorbent has been used to remove most of the highly fouling organic matter prior to desalination by double-staged NF [17].

On the other hand, several studies showed the potential risk to human health due to the accumulation of heavy metals in plants that used treated wastewater. Excessive accumulation of heavy metals in agricultural soils treated by irrigation wastewater threatens residents' lives who consume these crops or vegetables irrigated by wastewater [18]. Therefore, heavy metal levels were also investigated in the present paper.

In this study, the influent (raw wastewater after sand and gravel filter) and effluent (tertiary treated water by ultraviolet radiation) from Kabd WWTP in Kuwait are treated using an activated carbon filter (UF-AC) membrane. A quantitative analysis is performed to evaluate the suitability of the treated water by the UF-AC method for irrigation based on the recommended Kuwait Environment Public Authority (KEPA) standard limits. A comparative study is performed for conventional and UF-AC treatment methods through testing the water quality for influent and effluent samples before and after the treatment. Comprehensive chemical, biological, and heavy metal analyses are carried out to give a clear picture of the water quality. The economic analysis of the conventional methods and UF-AC technology is also presented in this study.

2. Methodology

2.1. Sample collection

Water samples were collected from Kabd WWTP. Four-liter samples were taken from different stages. The first sample was taken from the raw sewage sample after sand and gravel filter (Influent). The second sample was taken from the effluent sample released after the tertiary treatment by ultraviolet radiation. Water quality was investigated for both samples before and after passing it through the UF-AC membrane and analyzed. The measurements of the collected samples were performed at Kabd WWTP laboratories following standard methods for the examination of water and wastewater [19].

2.2. UF-AC membrane specification

UF-AC membrane was purchased from Indiamart. UF-AC membrane is a UltraPES hollow fiber membrane. It is made of polyether sulfone and consists of a distinctive 3-layer morphology that provides superior permeability and strength. UltraPES Polyethersufone (PES) hollow fiber membrane provides a retentive layer on the inner side of the hollow fiber membrane. It exhibits an extremely hydrophilic characteristic which reduces the potential of fouling. In addition, UltraPES shows a high caustic resistance and free chlorine tolerance allowing Liqui-Flux modules to operate at pH values between 1 and 13. PES membranes are known for their well-defined pore structure. UltraPES demonstrates this with its distinctive three-layer structure providing a highly porous support for the separation layer giving mechanical strength through thicker polymer ligaments and a protection layer on the outside with reduced pore-size to safeguard the overall membrane structure and integrity.

The pronounced asymmetric structure leads to an outstanding relation of permeability and retention rate. This allows UltraPES to achieve high volume flow at low transmembrane pressure and provides a unique way to reduce energy costs resulting in low operating costs particularly for larger filtration plants. Activated carbon filter is placed directly after the UF membrane.

The features and the benefits of the membrane includes excellent permeability, narrow pore-size distribution, low pressure requirements, low fouling potential, high temperature and chemical resistance (pH 1–13) and low energy consumption.

The membrane filter is a microbiological water filter which allowed to filter out bacteria to a minimum of 99.9999%, viruses to 99.99%, and cysts to a minimum of 99.9%. The filter will stop filtering water once it reaches the end of life. It uses a hollow fiber technology known as ultra-filtration technology which does not require the use of chlorine or chlorine dioxide for disinfection. The activated carbon filter with the membrane is used to remove taste, smell, and any odor present in the water. Fig. 1 shows a schematic diagram of the (a) UF-AC setup and (b) the internal membrane with an AC filter. The UF-AC membrane has a pore size of 15 nm. The membrane is operated at room temperature (22°C). UF-AC used in the test has a capacity of 750 mL with a flow rate of 2.5 L/min and 0.25 bar pressure. The specification and operating conditions of the UF-AC are summarized in Table 1.

2.3. UF-AC membrane cleaning

All parts should be cleaned of silt, debris, and any other contaminants. The meshes are designed to be backwashed for ease of cleaning. The removable filter can be taken out for cleaning when necessary.

In this study, the membrane was washed with pure water before use for 4 times using deionized water. The membrane was also cleaned after passing the influent and effluent water samples to avoid fouling the membrane. Membrane cleaning was performed by adding hydrogen peroxide (H_2O_2) at pH 9. After 6 h of static soaking, the membranes

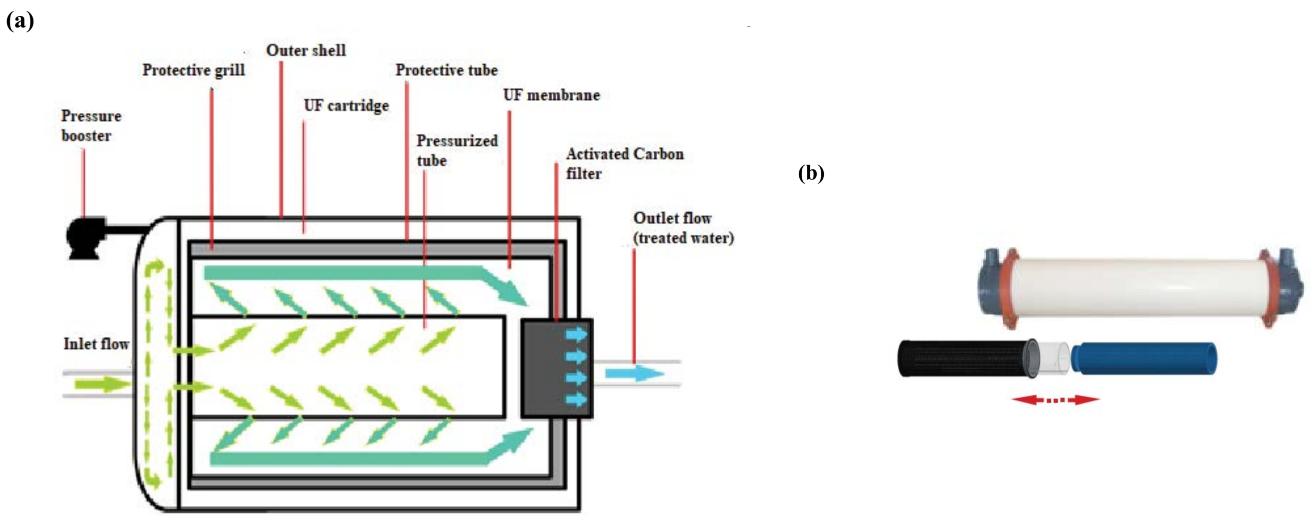

Fig. 1. Ultrafiltration membrane setup incorporated with an activated carbon filter. (a) UF-AC unit and (b) removable membrane with an activated carbon filter.

were then rinsed with deionized water to remove cleaning agent (H_2O_2).

2.4. Experimental system

The experiments were carried out in a laboratory scale UF-AC membrane system. The schematic diagram of the UF-AC experimental setup is shown in Fig. 1.

The setup consists of a pressure booster, base, pressurized tube, ultrafiltration membrane, and activated carbon filter. At the beginning of the experiment, the UF membrane was washed with deionized water. 500 mL of the feed water (influent, effluent) was poured into the ultrafiltration membrane vessel of the experimental setup after unscrewing the removable base. The base was then reattached, and the pressure was applied subsequently using a pressure booster for about five times the initial pressure (0.25 bar). The membrane top was opened, and the treated water flowed out at 2.5 L/min rate. The experiments were conducted at room temperature. The quantitative analysis for influent and effluent samples studied was repeated three times, and the average was calculated for the accuracy of the results.

2.5. Materials and methods

All chemicals were obtained from the Mushrif trading and contracting company in Kuwait. Deionized water was used for the preparation and dilution of metal solutions.

pH and conductivity were measured using HACH (model HQ11D) meter and HACH (HQ14D) meter, respectively. Chloride was determined using Titralab (model AT100 Series). Glass microfiber filter (model 934-AH, 47 mm diameter) was used for total suspended solids (TSS) and total dissolved solids (TDS) measurements, and the samples were heated after the filtration using Fisher Scientific Isotemp oven (model 655G) for TDS measurement. The vacuum pump for the filtration process was Vacuubrand (model MZ 2 C NT). Turbidity was analyzed using HACH (model 2100Q). Biological oxygen demand (BOD_5) was tested by 300 mL incubation glass bottle having a ground glass stopper and a flared mouth, where water was added to the flared mouth of special BOD_5 bottles, then a plastic cup was used over the flared mouth of the bottle to reduce evaporation of the water seal during incubation. The samples were placed in an incubator (Lab-Line Instruments) at 20°C ± 1°C for 5 d then the dissolved oxygen (DO) was determined using HACH DO Meter (model HQ30D Flexi) before and after the incubation period. HACH (model DR3900) spectrophotometer was used for measuring nitrate-nitrogen, ammonia-nitrogen, phosphate, and sulfate. The reagent used for ammonia was mineral stabilizer, alcohol dispersing agent, and Nessler Reagent. The reagents used for nitrate-nitrogen was NitraVer 5. Reagents used for sulphate, and phosphate were SulfaVer 4 and Amino Acid reagent (Cat No.193432), molybdate reagent (Cat No. 223632), respectively. All the reagents were Permachem reagents (PK/100). Chemical oxygen demand (COD) was measured by HACH DR3900 Spectrophotometer using LCK 514 (100–2,000 mg/L) and LCK 314 (15–150 mg/L) reagent. All reagents performed in the HACH spectrophotometer were from HACH Lange (Gmbh). Lovibond (model ET125) COD reactor was used for heating the sample. Samples were heated for 120 min. For microbiological analysis, an appropriate volume (100 mL) of an influent and effluent water sample from Kabd WWTP was filtered through a 47 mm, 0.45 µm pore size cellulose ester membrane filter that retains the bacteria present in the sample. The filter is placed on a 5 mL plate of Salmonella- Shigella agar using Himedia (M108-500 G) at 36.9°C ± 0.1°C. Total coliform was tested using Endo Agar using Himedia (M029-500 G) at 36.9°C ± 0.1°C. Fecal coliform (Himedia, M1122-500 G) was tested and was performed under 44.5°C ± 0.1°C. All samples were then placed in the bicategorical (Raypa) incubator. Dilution was performed for influent sample 60 times for total coliform, 50 times for fecal coliform and 40 times for Salmonella. Commercially available H_2O_2 (~30% in weight) were purchased from Tianli Chemical Reagent Co., (Tianjin, China). The raw sewage was taken after sand and gravel filter (Influent). The second sample was taken from the effluent sample released after the tertiary treatment by ultraviolet radiation. The experiments were conducted for a period of 3 months from January to march, the samples were collected in the morning time at 8.00 am.

Calibration was done for all instruments before use. Dilution was performed for influent samples with high turbidity and conductivity levels by distilled water to prevent plugs or damaging the instruments. The suitability of the municipal effluents for agricultural reuse was then evaluated and compared with the standards of KEPA.

2.6. UF-AC treatment process

Fig. 2 shows the treatment process performed in our study. Wastewater samples from Kabd wastewater treatment plant were passed through the sand and gravel filter. The influent samples were taken after grid removal. The influent sample was then passed through the UF-AC membrane to get the influent sample after UF-AC membrane. The influent sample was sent to the aeration zone and then to settler to allow the settling and the sludge removal. The wastewater was then sent to the ultraviolet treatment. The effluent samples were then taken after the ultraviolet treatment. Effluent samples were then passed to the UF-AC membrane. Influent and effluent samples were taken before and after the UF-AC treatment for analysis.

3. Results and discussions

In the present work, the effectiveness of the UF-AC membranes for treatment of influent (raw wastewater after sand and gravel filter) and effluent (tertiary treated water by ultraviolet radiation) water sample from Kabd WWTP was assessed. The quantitative analysis of the wastewater for the influent and effluent samples by UF-AC and by conventional methods involved the determination of its pH, TSS, COD, BOD_5, TDS, turbidity, conductivity, DO, nitrate-N, ammonia-N, sulfate, phosphate, and chloride as well as for the microbiological tests (total coliform, fecal coliform, and Salmonella) and heavy metals. Table 2 present the average results with the standard deviation of the analysis for influent and effluent samples treated by conventional and UF-AC method.

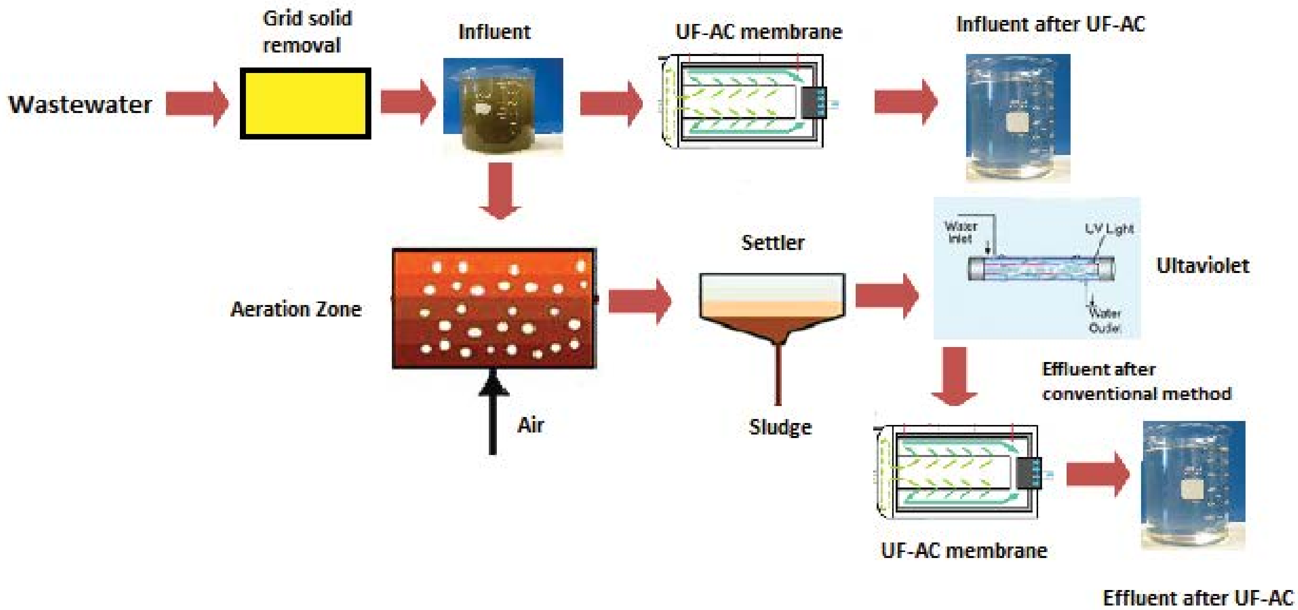

Fig. 2. Membrane treatment process.

Table 1
UF-AC specification and operating conditions

UF-AC specification	Operating conditions
Optional insertion	Activated carbon filter disk
Pore size of the membrane	15 nm
Pore diameter	0.9 mm
Volume before replacing the cartridge	6,000 L before replacement
Molecular weight cutoff	30 KDa
Operating temperature	22°C
Capacity	750 mL
Initial flow rate	2.5 L/min
Operation pressure	0.25 bar
Average flux	50–110 LMH
Flow configuration	in to out
Bacterial and virus removal	Bacterial removal Log 6, Virus removal log 4
Membrane area	0.7 m^2
Maximum pressure at inlet	45 psi
Operational mode	Crossflow filtration
Temperature range	0°C–40°C
Maximum backwash pressure	30 psi

Comparison of the results with the recommended KEPA standard guidelines limits was investigated to assess the suitability of the treated wastewater for irrigation purposes. All the results are presented in Table 2. pH was 7.43 for the influent sample and it is raised to 7.73 using the UF-AC system. However, the effluent by the conventional method showed a pH of 7.58, indicating that the UF-AC membrane increased the pH value more than the conventional method. Also, the effluent pH was raised to 7.68 by UF-AC. The results for both methods fall within the appropriate KEPA standard limits (6.5–8.5) for irrigation. These values are in the normal range based on FAO standards guidelines for irrigation. pH at this range can prevent scale formation in irrigation equipment and provides effective chemical disinfection.

The variation of the initial and the final results for TSS, COD, BOD_5 for influent and effluent treated by UF-AC and conventional method. UF-AC treatment method were very effective in reducing the TSS, COD, and BOD_5 concentrations. While the influent wastewater had TSS, COD, and BOD_5 values of 184, 485, and 241.8 mg/L, respectively, for influent wastewater treated by UF-AC the values were reduced to 3, 70, and 20 mg/L by UF-AC, correspondingly.

These were equivalent to reduction percentages of about 98.37% for TSS, 85.57% for COD, and 91.73% for BOD_5. However, for the conventional method the values for TSS, COD, and BOD_5 were reduced to 20, 34.1, and 20.3 mg/L that shows that UF-AC has a better performance for TSS and a quite similar efficiency for BOD_5 removal compared to the conventional treatment, whereas the reduction was higher in COD values for the conventional method. Further treatment is required to match the KEPA standard limits. Besides, further reduction percentage was shown for the treated effluent treated by UF-AC that is 100% for TSS and 97.35% for BOD_5. No further reduction was observed for COD treated by the conventional method. Furthermore, for influent and effluent samples treated by UF-AC, the values were lower than the KEPA standard guidelines limits indicating that that treated wastewater can be used for irrigation.

TDS, conductivity, turbidity, and DO for influent and effluent treated by conventional and UF-AC method. The TDS, conductivity, and turbidity level for influent wastewater sample treated by UF-AC was reduced from 1,120 mg/L, 2220 μS/cm and 254 (NTU) to 960 mg/L (14.29%), 1,093 μS/cm (50.77%) and 0.39 NTU (99.85%), respectively. However, the results for TDS, conductivity, and turbidity for the influent treated by the conventional method were reduced to 910 mg/L (18.75%), 1,160 μS/cm (47.75%), and 7.93 NTU (96.88%), respectively. High reduction of turbidity was similarly shown recently [7]. TDS, conductivity, and turbidity after further treatment of effluent sample by UF-AC reduced to 870 mg/L (4.40%), 1,041 μS/cm, and 0.35 NTU (95.59%), respectively. TDS is a very important parameter for irrigation, as high salinity concentration could result in soil degradation and have an impact on plant growth [20]. DO for the influent sample treated by the conventional method was 0.49 mg/L and it was increased to 8.54 mg/L using the UF-AC method whereas, the effluent treated by the conventional method was increased to 6.90 mg/L. Furthermore, as can be seen in Fig. 3d, the effluent DO was increased to 8.92 mg/L using UF-AC. DO concentration is a key parameter for characterizing natural and wastewater and it heavily affects the global state of the environment [21]. The quantity of DO regulates the production of substances that repress diseases and pathogens. The DO analysis in this study showed that the UF-AC was more effective in increasing the DO level for both influent and effluent samples compared to the conventional treatment. The analysis results for TDS, conductivity, turbidity and DO for effluent samples treated by conventional and UF-AC method fall within the recommended KEPA standards guideline limits for irrigation.

In Table 2, the nitrate-nitrogen, and ammonia–nitrogen concentrations in the influent wastewater sample treated by the conventional method were 27.5 and 29.9 mg/L, respectively. The nitrate–nitrogen, and ammonia-nitrogen in influent sample treated by UF-AC was reduced to 4.1 mg/L (85.09%), and 29.6 mg/L (1.00%), respectively and the effluent samples treated by conventional method, nitrate–nitrogen, and ammonia-nitrogen were reduced to 1.4 mg/L (94.91%), and 20.3 mg/L (32.11%), respectively. Further reduction to nitrate–nitrogen, and ammonia-nitrogen in effluent treated by UF-AC resulted to 0.8 mg/L (42.86%), and 13.5 mg/L (33.5%). Nitrate is essential for growth and reproduction but excessive levels of nitrogen cause delay of maturity in certain crops and prolong the vegetation stage, making the crop more susceptible to pests and diseases and subsequently leading to lower yields. The concentration of nitrate in the treated influent and effluent samples should be less than 5 mg/L to be used for irrigation. It has been reported that the nutrients in recycled water could replace fertilizers and can improve plant growth and crop yields and at the same time, the concentration should be monitored to avoid accumulation [20–23].

Sulfate, phosphate and chloride concentration for influent wastewater sample treated by UF-AC were reduced from 122, 19.8 and 950 mg/L to 103 mg/L (15.57%), 12.3 mg/L (37.88%), and 253.6 mg/L (73.31%) respectively as shown in Table 2. Whereas for the effluent sample treated by conventional method sulfate, phosphate, and chloride were reduced to 108 mg/L (11.47%), 10.1 mg/L (48.99%), and 260 mg/L (72.6%), respectively. Moreover, the concentration for effluent sample treated by UF-AC was reduced further to 101 mg/L (6.48%), 6.3 mg/L (14.75%), and 183.9 mg/L (29.2%), respectively. High levels of chloride and sulfate can affect the crop and the soil. In the literature bearing on the toxicity of chloride and sulfate salts, plants are reduced in size by these salts, and reductions in yield were observed. Irrigated water with high sulfate salts can affect sensitive crops by limiting the uptake of calcium and increasing the adsorption of sodium and potassium, resulting in a disturbance in the cationic balance within the plant [13,14].

Besides, an excessive amount of phosphate causes plants to grow poorly, reduces the plant's ability to take up required micronutrients and die [24].

Many disease-causing viruses, parasites, and bacteria are also present in wastewater and can penetrate almost anywhere in the community. Hence there are compelling reasons to treat wastewater to reduce the risk of transmitted diseases and environmental pollution [25]. In the present work, the microbiological investigation was performed for total coliform, fecal coliform, and Salmonella, and the results are shown in Table 2. The average number of total coliform, fecal coliform, and Salmonella found in the influent sample treated by the conventional method were 6.7×10^9 CFU/mL, 2.5×10^8 CFU/mL, and 6.7×10^9 CFU/mL, respectively. The values were reduced to 3.0×10^2 CFU/mL, 7.2×10^1 CFU/mL, and 5.9×10^1 CFU/mL by UF-AC treatment. These were equivalent to the average removal of 99.99% for total coliform, fecal coliform, and Salmonella. The results indicated that the UF-AC membrane with a pore size of 15 nm showed slightly higher removal efficiency than the conventional treatment due to the large surface area of the UF membrane. For the effluent treated by conventional method the values were reduced to 4.6×10^7 CFU/mL (99.31%), 1.2×10^6 (99.52%), and 3.9×10^6 CFU/mL (99.94%), respectively. This was indicated similarly in recent study [8]. Moreover, the values for the effluent treated with UF-AC were further diminished to 97.87% for total coliform and 100% removal for fecal coliform and Salmonella. The bacteria removal measured in this work was of the same order of magnitude as similar work in the literature using ultrafiltration membrane [26]. The results for all microbiological tests adhere to the recommended KEPA limits for irrigation. Also, World Health Organization (WHO) recommends that only treated wastewater with a total most probable number (MPN) of less than 100 colonies per 100 mL in 80% of the samples examined can be utilized for irrigation.

The results revealed that the treatment using UF-AC and conventional method adheres to KEPA standard limits. As demonstrated, the quality of the treated wastewater by UF-AC is suitable for agriculture irrigation. Furthermore, by comparing the results for influent and effluent after UF-AC treatment with FAO guidelines, the suitability of the treated water for irrigation is confirmed [27].

3.1. Limitations

UF-AC showed some limitations that could be improved in further studies particularly for TDS, sulfate, and COD analysis. However, the results were within the KEPA standard limits for irrigation. No superior reduction was shown after the effluent treatment due to the presence of salt particles that were not completely removed in the treatment. A future recommendation for lowering COD concentration is by adding hydrogen peroxide to the water in small concentrations (300–500 mg/L) and subject it to UV treatment. This combination of processes may oxidize organic and inorganic matter present in the wastewater [28]. Biological absorption by microalgae is a mild and environmentally friendly method for TDS removal [29]. Sulfate ions can be removed from wastewater using Ettringite precipitation method [30].

3.2. Economic analysis

State of Kuwait has a land area of 17,818 km^2 with a population of 3.6 million and has three sources of water namely, sea water, ground water, sewage and industrial water. After desalination sea water is the main source of drinking water in Kuwait, where ground water and treated wastewater are used for agricultural and industrial purposes. Thus, Kuwait has to rely on the costly seawater desalination process to meet its water demand, which is growing rapidly due to population growth and urbanization.

The analysis of the economic feasibility of reusing wastewater for non-potable urban purposes is of great interest both for the national economy and for the entity that exploits this resource. The use of the resource of WWT, which is closely linked to the size of the population were, the rate of water consumption in Kuwait is increasing, and that it is considered one of the highest rates in the world, noting that the per capita consumption of water reaches 600 L/d serving more than 3.6 million people. Therefore, annual total cost of Kuwait is based on its population was estimated around US$ 264 million for secondary treated wastewater, US$ 328.5 million for tertiary treated effluent, and US$ 450 million for advanced treated wastewater (UF and RO) compared with US$ 1.752 billion for desalinated water as shown in Fig. 3. Therefore, to use advanced treated effluent would cost the country US$ 121.5 million a year more than using tertiary treated effluent. And using desalinated water would cost US$ 1.4235 billion and US$ 1.302 billion a year more than using tertiary and advanced treated effluents respectively. As the capital and operating costs of seawater desalination plants increase, the economic benefit of reuse will increase also. These numbers suggest that a wider range of uses of treated effluents should be given serious consideration [31,32].

This amount was calculated for WWTPs that cover different technologies, based on the published literature, the cost for each type of effluent treatment, thus the cost per 4.545 m^3 and the cost per person per day and per year can be calculated as shown in Fig. 3.

Furthermore, Fig. 3 also shows the economic analysis for different WWTP conventional methods and for advanced UF and RO compared to the UF-AC system. As can be seen in Fig. 3, UF membrane combined with AC not only needs less space but also costs less as compared to the Secondary, Tertiary, UF-RO and Desalinated water which makes it highly recommended for practice in Kuwait, instead of the current conventional method.

Compared to conventional technology, UF will provide the following benefits:

- Shorter construction time is an important factor, when the construction time can be decreased, the plant can produce water for a longer time, this reflects in an increase in net production.

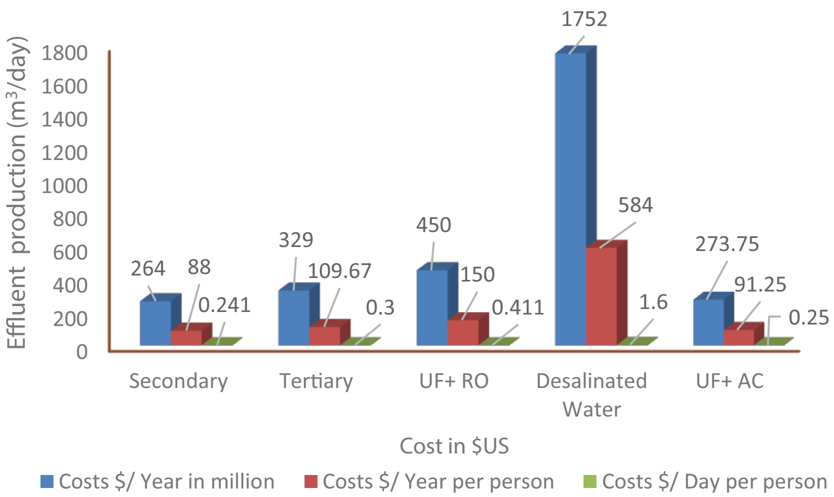

Fig. 3. Cost of daily effluent production limits.

Table 2
Quality of influent and effluent under UF-AC and conventional treatment methods

Test	Influent (a)	Influent after UF-AC	Effluent after conventional	Effluent after UF-AC	Reduction % between influent and influent by UF-AC	Reduction % between influent and effluent by conventional	Reduction % between effluent and effluent by UF-AC	KEPA standard limits
pH	7.43 ± 0.45	7.73 ± 0.53	7.58 ± 0.5	7.68 ± 0.55	NA	NA	NR	6.5–8.5
TSS, mg/L	184 ± 5.31	3 ± 0.21	20 ± 1.52	0	98.37	89.13	100	15
COD, mg/L	485 ± 11.14	70 ± 6.4	34.1 ± 2.83	50 ± 4.65	85.57	92.97	NR	100
BOD_5, mg/L	241.8 ± 6.9	20 ± 1.74	20.3 ± 1.8	6.4 ± 0.91	91.72	91.6	68.47	20
TDS, mg/L	1,120 ± 19.5	960 ± 16.72	910 ± 15.95	870 ± 15.35	14.29	18.75	4.4	1,500
Conductivity, µS/cm	2,220 ± 39.22	1,093 ± 19.3	1,160 ± 20.52	1,041 ± 18.56	50.77	47.75	10.26	–
Turbidity, NTU	254 ± 7.35	0.39 ± 0.03	7.93 ± 0.41	0.35 ± 0.04	99.85	96.88	95.59	–
Dissolve oxygen, mg/L	0.49 ± 0.038	8.54 ± 0.62	6.9 ± 0.32	8.92 ± 0.61	NR	NR	NR	>2
Nitrate - N, mg/L	27.5 ± 2.11	4.1 ± 0.57	1.4 ± 0.22	0.8 ± 0.18	85.09	94.91	42.86	15
Ammonia - N, mg/L	29.9 ± 1.91	29.6 ± 1.85	20.3 ± 1.4	13.5 ± 0.95	1.003	32.11	33.5	15
Sulfate, mg/L	122 ± 2.56	103 ± 2.42	108 ± 2.45	101 ± 2.35	15.57	11.47	6.48	–
Phosphate, mg/L	19.8 ± 1.53	12.3 ± 1.44	10.1 ± 1.12	6.3 ± 0.92	37.88	48.99	37.62	30
Chloride, mg/L	950 ± 16.45	253.6 ± 3.5	260 ± 3.64	183.9 ± 2.45	73.3	72.6	29.2	<300
Total coliform, CFU/mL	6.7×10^9	3.0×10^2	4.6×10^7	3	99.99	99.31	97.87	400
Fecal coliform (MPN/100), CFU/mL	2.5×10^8	7.2×10^1	1.2×10^6	0	99.99	99.52	100	20
Salmonella (MPN/100), CFU/mL	6.7×10^9	5.9×10^1	3.9×10^6	0	99.99	99.94	100	NA

NR – No reduction; NA – Not available.

- Other fixed costs, such as land purchase, etc. could be reduced as well when conventional pretreatment is replaced with UF membrane technology.

In addition, the UF pretreatment provides the following non-quantifiable benefits:

- Less construction risk. The UF pretreatment needs substantially smaller civil works.
- Smaller footprint. Apart from cost savings in land purchase, this provides additional benefits, such as a greater freedom of choice for site location and potentially easier permitting for civil constructions.

4. Conclusion

Kuwait has a desert climate characterized by a long, dry, hot summer, with temperatures reaching more than 45°C and therefore the use of treated wastewater for irrigation is highly recommended to compensate for the water deficit. The country is considering water recycling as a vital non-conventional water source to reduce the consumption of expensive desalinated water and reduce overtaxing of depleted aquifers. The hybrid process of incorporating carbon filter with UF membrane investigated in this study turned out to be highly efficient and effective for rejecting most of the harmful constituents of the untreated wastewater with less cost compared to other WWTP methods. The treated influent by UF-AC membrane indicated high removal of TSS (98.37%), COD (85.57%), BOD_5 (91.73%), turbidity (99.85%), and nitrate – N (85.09%),. Total coliform, fecal coliform, and Salmonella were also removed efficiently reaching average removals of 99.99% by UF-AC membrane due to its high rejection and large surface area. The quantitative analysis indicated that the UF-AC method exhibited similar and sometimes better contaminants removal in comparison with the conventional method for the measured parameters (pH, TSS, BOD_5, TDS, turbidity, conductivity, DO, nitrate-N, sulfate, chloride, and microorganisms). The quality of the treated water fell within the range set out by KEPA standards, despite the ammonia concentration levels not being removed from the treated wastewater samples. The treated water can be safely used for irrigation. Therefore, the UF-AC treatment method can be used either as a primary step for treating the influent wastewater or after the tertiary stage for complete disinfection.

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Declarations

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Conflicts of interest/Competing interests

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