A Comparative Study of Membrane and Extended Aeration Activated Sludge Pilot Scale Sewage Treatment Plant in Gassim Area, Kingdom Of Saudi Arabia

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***Abstract*—** There were 2 wastewater treatment pilot plants were operated for 36 weeks in Al Gassim region in the period from January 2010 till end of September 2011. The two pilot plants are extended aeration (ASEA) and Membrane Bioreactor (MBR). The influent COD concentration to the MBR pilot ranges from 212 mg/l to 401 mg/l and the removal efficiency ranges between 93% and 98%. The concentration of BOD5 in the influent to the MBR pilot plant ranges from 179 mg/l to 328 mg/l and the removal efficiency of BOD5 ranges from 96% to 97%. The concentration of SS in the influent to the MBR pilot plant ranges from 183 mg/l to 241 mg/l and the removal efficiency of SS ranges from 95% to 98%.

The influent COD concentration to the Activated Sludge Extended Aeration (ASEA) pilot plant ranges from 212 mg/l to 401 mg/l and the COD removal efficiency ranges between 89% and 91%. The concentration of BOD5 in the influent to the ASEA pilot plant ranges from 179 mg/l to 328 mg/l. and the removal efficiency of BOD5 ranges from 93% to 95%. The concentration of SS in the influent to the ASEA pilot plant ranges from 183 mg/l to 241 mg/l and the removal efficiency of SS ranges from 93% to 97%. The effluent concentration of TSS ranges from 6 to 17 mg/l.

The effluent quality from MBR pilot plant is better than that from activated sludge pilot plant.

***Keywords*—** Activated sludge, extended aeration, membrane bioreactor.

I. INTRODUCTION

THE sources of water in Kingdom of Saudi Arabia are ground water, rain water and sea water. Due to water scarcity in the Kingdom, the Government put huge investments in executing desalinized water plants, so that desalinized water can be used as additional source for domestic water. The Saline Water Conversion Corporation (SWCC) owns and operates 220 units in 46 locations, with a combined capacity of approximately 3.5 Mm3/day. The available capacity is estimated at 2.9 Mm3/day of desalinized water (World Bank 2003). The production of desalinized water reaches up to almost 50% of all the urban water used in the kingdom.

In the year 1995 the total municipal wastewater collected in the Kingdom was estimated at 1017 MCM, of which 418 MCM were treated using secondary level or better [2]. In 2005, the quantity of treated wastewater reached up to 1.5 million m3/day using secondary and tertiary methods, out of which 340,000 m3/day is used for irrigation in farms and green areas in and around the main cities, [13].

The advanced treated water capacity in Saudi Arabia is growing rapidly. In the year 2001, the reclaimed (treated) wastewater available in Saudi Arabia amounted to 674 Mm3/yr (1.85 Mm3/day) ,of which only 36% is used in irrigation while the remaining is discharged to land (34%), disposed to sea (18%), and about 12% is reused for industrial purposes, groundwater recharge and landscape irrigation (Al-Morgin, 2001). However, Al Tokhais estimated the volume of treated wastewater in the major urban centres to be around 474.4 Mm3/year (1.3 Mm3/day), of which 30%-40% is treated to the tertiary level [1]. Regarding the wastewater reuse status in 2003, [15] stated in their report that only a small fraction of the treated wastewater is reused (16%), mostly for irrigation and other minor uses in industry, public parks and landscape irrigation (World Bank, 2003). At present, the total treated wastewater produced amounts to 1032.95 Mm3/yr. (2.83 Mm3/day), with an increase of 53% compared to the year 2001.The number of wastewater treatment plants in operation in the kingdom reached 65 stations, with an average design treatment capacity of approximately 3.31 Mm3/day. The maximum quantity of treated wastewater from a single station amounts to 290000 m3/day, and is produced by Riyadh southern station, followed by the Dammam treatment station with a treated water production of 280000 m3/day.

For save and feasible reuse of treated wastewater, the quality of treated wastewater shall comply with the National Code of Reuse in the Kingdom of Saudi Arabia. The quality of treated wastewater depends mainly on the wastewater treatment process which utilized. This research will focus on the quality of treated effluent produced from two wastewater treatment processes: (I) Activated Sludge Treatment Process (Extended Aeration System) and (II) Wastewater Treatment using Membrane Bioreactor (specifically Zee Weed).

This research was conducted on two pilot plants; the first

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pilot plant utilized Zee Weed Membrane system and the second pilot plant utilized Activated Sludge Treatment process (Extended Aeration System). Both plants were located at Buraida Wastewater Treatment Plant in the city of Buraida, Al Gassim, Saudi Arabia.

The specific objectives of this research are to compare between the quality of treated wastewater effluent produced from wastewater treatment plants utilized membrane units and that produced from wastewater treatment plants utilized activated sludge treatment process (extended aeration system) and identify which of them are complying with the National Code of Reuse in the Kingdom of Saudi Arabia.

II. MATERIALS AND METHODS

There were two pilot plants used in this research; MBR and activated sludge extended aeration pilot plants. Herein after are the descriptions of the two pilot plants.

A. MBR Pilot Plant

Fig. 1 illustrates the schematic flow diagram of MBR pilot plant. The influent wastewater flow to the pilot plant ranged from 300 to 450 liter/day. The MBR pilot plant operated for 36 weeks starting from January 2010 to the end of September 2010. The samples were collected 5 days per week. The total number of collected and analyzed samples was 180 samples.

TABLE I
MAIN FEATURE OF THE MBR UNIT

Item Description	No. And Dimensions	Item Description	No. And Dimensions
MBR unit (membrane module)	One (1) unit with effective area 0.9 m2	Reject discharge pump	One (1) unit
HDPE tank complete with valves, temperature indicator	Tank volume 189 liter	Process control valve	One (1) unit
Air blower with air flow indicator	Capacity of $1.98*10^{-3}$ m3/sec	Central control panel with solid state controller	One (1) unit
Back pulse HDPE tank complete with valves and permeate discharge overflow	Tank volume 19 liter	Epoxy coated carbon steel frame	One (1) unit
Dimensions of the pilot Plant	1070mm length, 660 mm width and 1580mm height,	Weight of the pilot plant	212 kg
F/M	0.2	Back pulse Frequency	Every 15 Minutes in phase 1 & 2
Air flow	$9.439*10^{-4}$ m3/sec	Back pulse Duration	15 Seconds in phase 1 & 2

B. ASEA Pilot Plant

The extended aeration activated sludge pilot plant consists mainly of aeration tank, clarifier, and filtration unit and control panel. The volume of the aeration tank is 1200 liters. This tank is provided with diffused air from air blower with capacity of 120 liter/min. The aeration tank is equipped with air pipes and diffusers. The mixed liquor flows from aeration tank to the final clarifier. The capacity of final clarifier is 220 liter. The activated biomass is settled at the bottom and pumped to the aeration tank by using air lift pump. The clarified effluent flows to the sand filter unit. The filtered water stored in a tank with capacity of 100 liters. The whole process was controlled using PLC system. Fig. 1 shows the flow line diagram of extended aeration pilot plant.

The extended aeration pilot plant operated for 36 weeks starting from January 2010 to the end of September 2010. The samples were collected 5 days per week. The total number of collected and analyzed samples was 180 samples. The extended aeration pilot plant was running at the following operating parameters.

Airflow	0.057 m3/min
F/M	0.2
Flux	10 g/d

TABLE II
CHARACTERISTICS OF THE INFLUENT FLOW TO BOTH PILOT PLANTS

Parameter	Concentration, (mg/l)	Load (kg/day)
Influent BOD5	300	0.45
Influent Total Suspended Solid (TSS)	300	0.45
Volatile Suspended Solid (VSS)	255	0.3825
Total Kjeldahl Nitrogen	40	0.06
Ammonia Nitrogen (NH4-N)	30	0.045
Phosphorus (P)	12	0.018
Influent Flow to the Pilot Plant		
Average Flow (Q Average), m3/day	1.5	
Peak Flow (Q Peak), m3/h	0.25	

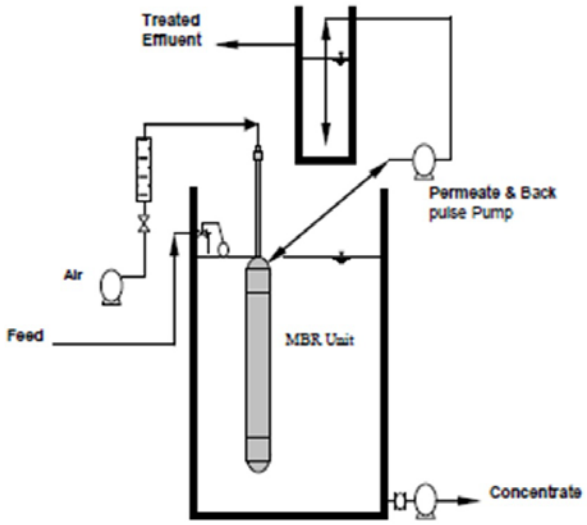

Fig. 1: Schematic Diagram of MBR Pilot Plant

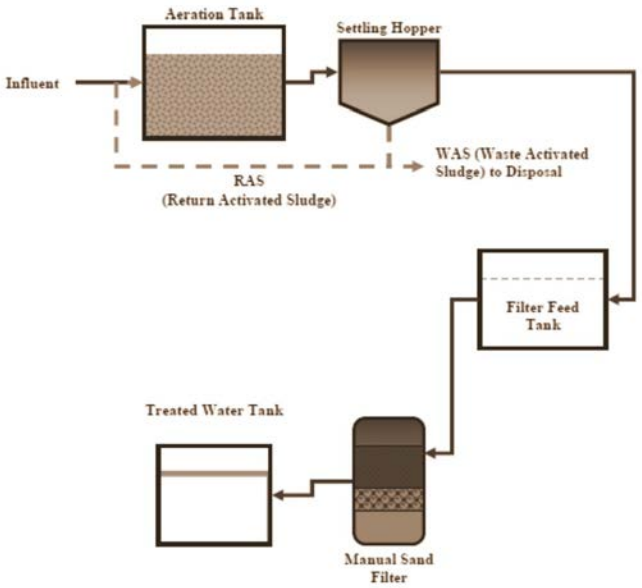

Fig. 2: Process Flow Diagram of Extended Aeration Pilot Plant

All analyses were performed according to procedure described in Standard Method for the Examination of Water and Wastewater [17].

III. RESULTS

These are the results and discussions of the results from both plants

A. MBR Pilot Plant

The graphs in this chapter illustrate only 36 samples in each graph (each sample is the average of results for each week). The characteristics of the influent and clarified effluent from the MBR pilot plant are shown in the following Figures. Figure 4.1 shows the influent and effluent COD concentration for different samples collected from the pilot plant. The influent COD concentration ranges from 212 mg/l to 401 mg/l and effluent COD concentration ranges from 4 mg/l to 28 mg/l. The COD removal efficiency ranges between 93% and 98%.

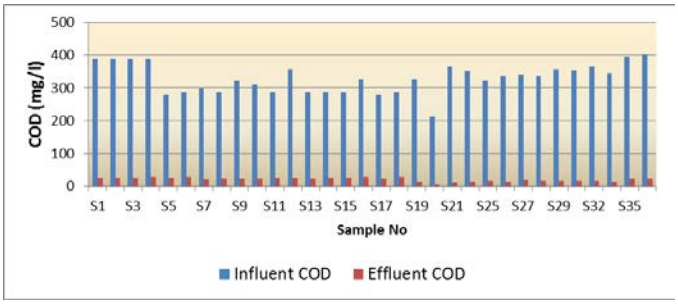

Fig. 3(a): Influent and Effluent COD from MBR Pilot Plant

The concentration of BOD5 in the influent to the MBR pilot plant ranges from 179 mg/l to 328 mg/l as shown in Figure 4.2. The BOD concentration in the treated effluent does not exceed 14 mg/l. The removal efficiency of BOD5 ranges from 96% to 97%.

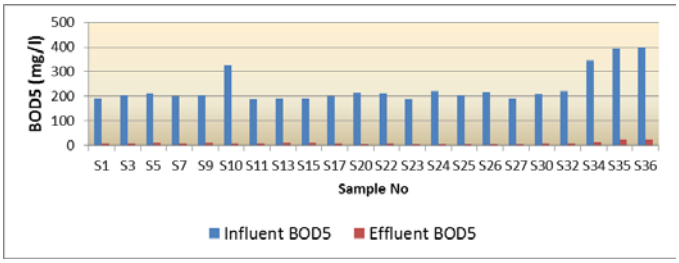

Fig. 3(b): Influent and Effluent BOD5 from MBR Pilot Plant

The concentration of SS in the influent to the MBR pilot plant ranges from 183 mg/l to 241 mg/l as shown in Figure 4.3. The treated effluent is very clear and the concentration of SS does not exceed 11 mg/l. The removal efficiency of SS ranges from 95% to 98%.

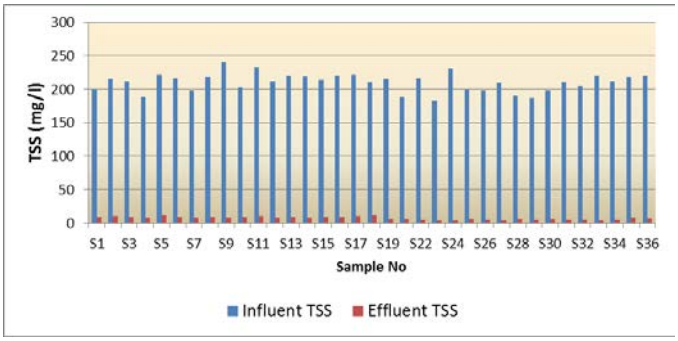

Fig. 3(c): Influent and Effluent SS from MBR Pilot Plant

The concentration of ammonia in the influent to the MBR pilot plant ranges from 18 mg/l to 25 mg/l as shown in Figure 4.4. The removal efficiency of ammonia ranges 44% to 98%. The low removal efficiency of ammonia could be attributed to the high organic load influent to the pilot plant which utilizes the oxygen for its degradation and there is no enough oxygen for nitrification process to be completed.

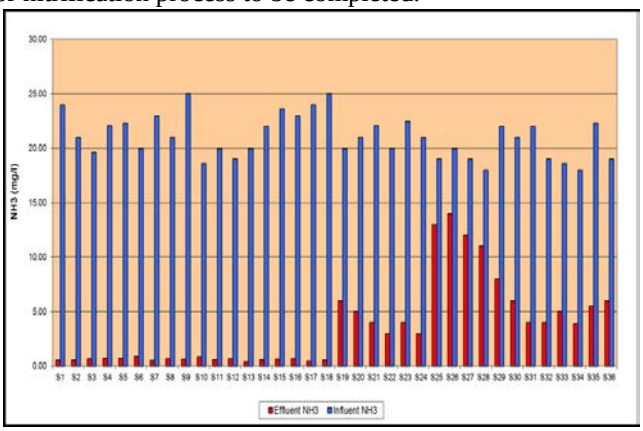

Fig. 3(d): Influent and Effluent Ammonia from MBR Pilot Plant

B. ASEA Pilot Plant

The graphs in this chapter illustrate only 36 samples in each graph (each sample is the average of results for each week). The characteristics of the influent and clarified effluent from the Activated Sludge Extended Aeration (ASEA) pilot plant are shown in the following Figures. Figure 4.5 shows the influent and effluent COD concentration for different samples

collected from the pilot plant. The influent COD concentration ranges from 212 mg/l to 401 mg/l and effluent COD concentration ranges from 24 mg/l to 39 mg/l. The COD removal efficiency ranges between 89% and 91%. The effluent COD ranges from 24 mg/l to 39 mg/l.

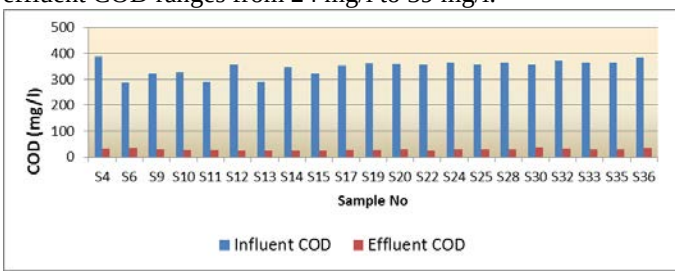

Fig. 4(a): Influent and Effluent COD from ASEA Pilot Plant

The concentration of BOD5 in the influent to the ASEA pilot plant ranges from 179 mg/l to 328 mg/l as shown in Figure 4.6. The BOD concentration in the treated effluent does not exceed 18 mg/l. The removal efficiency of BOD5 ranges from 93% to 95%.

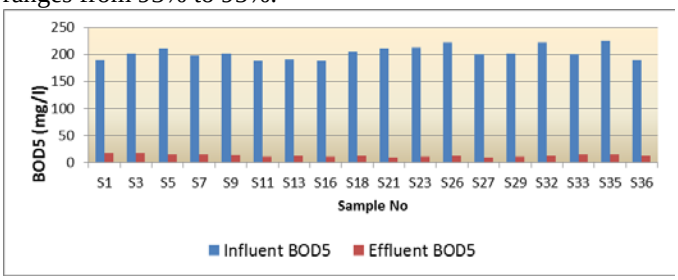

Fig. 4(b): Influent and Effluent BOD5 from ASEA Pilot Plant

The concentration of SS in the influent to the ASEA pilot plant ranges from 183 mg/l to 241 mg/l as shown in Figure 4.7. The treated effluent is very clear and the concentration of SS does not exceed 17 mg/l. The removal efficiency of SS ranges from 93% to 97%. The effluent concentration of TSS ranges from 6 to 17 mg/l.

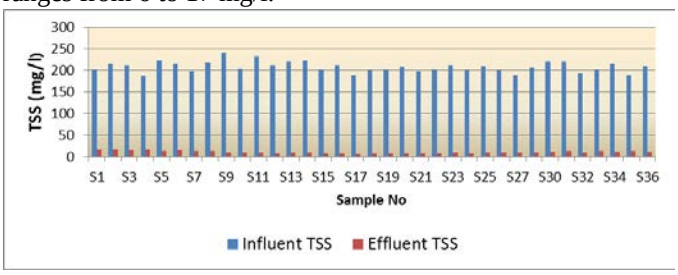

Fig. 4(c): Influent and Effluent TSS from ASEA Pilot Plant

The concentration of ammonia in the influent to the MBR pilot plant ranges from 18 mg/l to 25 mg/l as shown in Figure 4.8. The removal efficiency of ammonia ranges 19% to 97%. The low removal efficiency of ammonia could be attributed to the high organic load influent to the pilot plant which utilizes the oxygen for its degradation and there is no enough oxygen for nitrification process to be completed.

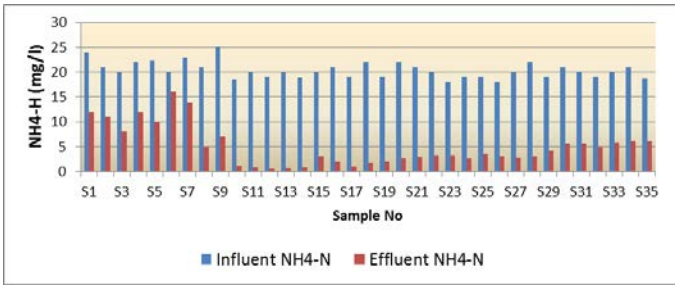

Fig. 4(d): Influent and Effluent Ammonia from ASEA Pilot Plant

IV. CONCLUSIONS

The influent COD ranges from 212 mg/l to 401 mg/l for both pilot plants. In case of MBR, The concentration of COD in the effluent ranges from 4 mg/l to 28 mg/l and the COD removal efficiency ranges between 93% and 98%. In case of ASEA pilot plant, the concentration of COD in the effluent ranges from 24 mg/l to 39 mg/l with removal efficiency ranges from 89% to 91%.

The concentration of influent BOD ranges from 179 mg/l to 328 mg/l. In Case of MBR The concentration of BOD in the effluent ranges from 5.1 mg/l to 14 mg/l and the COD removal efficiency ranges between 96% and 97%. In case of ASEA pilot plant, the concentration of BOD in the effluent ranges from 9 mg/l to 18 mg/l with removal efficiency ranges from 93% to 95%.

The high removal efficiency of organic matter could be attributed to the fact that organic matter can be highly degraded in both MBR and ASEA pilot plants. It can be seen also that capacities of BOD and COD removal were high from the beginning of the experiment. This indicated that the heterotrophic bacteria which responsible of degrading the carbonaceous components, were enriched in the aerobic part of the reactor because the reactor was fed with a domestic sludge from Qassim sewage treatment plant for two weeks before starting the experiment. During this period the heterotrophic bacteria was acclimatized with the incoming influent. The results obtained in this research are in agreement with results obtained by [16] who have conducted a study using an intermittent aeration in MBR with volumetric loading rate ranges between 0.62 to 0.7 kg COD m3/d and the removal efficiencies from 97 to 98%. Also, Reference [18] have carried out a study using staged anaerobic and aerobic MBR with the volumetric loading rate of 1.25 kg COD m3/d and the removal efficiency was 97%.
Reference [10] operated MBR plant for 100 days. The influent COD fluctuated from 140 and 1150 mg/l. However, the filtrate COD was maintained at a low level, generally less than 25 mg/1. Taking the 100 days of the experiment as a whole, the removal percentage of COD varied in the range of 83.3% and 99.3%. It was shown that the best results were obtained at the SRT of 50 d. The COD removals were between 83.3-97.8% at the organic loads in the range of 0.016 and 0.2 kg COD/m3.d, between 90.5-99.3% at the organic loads in range of 0.2 and 0.4 kg COD/m3.d, above 94% at the organic loads in range of 0.4 and 0.6 kg COD/m 3.d, and above 98% at the organic loads in range of 0.6 and

0.8 kg COD/m3.d. This clearly indicated that the MBR had a potential in treating high-strength urban wastewater.

Also It is noticed that the effluent quality from MBR pilot plant is superior the quality effluent from ASEA pilot plant. Reference [12], reported that there have been several investigations on treatment efficiencies of MBR and activated sludge processes operating under comparable conditions that have shown significantly improved performance of an MBR in terms of COD, NH3-N and SS removals, [18]

Reference [16] reported that the COD removal efficiency was about 97%. The results shown that there was no significant difference on COD removal efficiency although operated with varying aeration and non-aeration time. This indicates that organic matter can be degraded under both aerobic and anaerobic conditions. The performance of the MBR on organic removal appears to be relatively insensitive to the cycle time, whereas it resulted in high COD removal efficiency.

The SS concentrations in the influent and effluent from both MBR and ASEA pilot plants. The concentration of influent SS ranges from 183 mg/l to 241 mg/l. In Case of MBR, The concentration of SS in the effluent ranges from 4 mg/l to 11 mg/l and the SS removal efficiency ranges between 95% and 98%. In case of ASEA pilot plant, the concentration of SS in the effluent ranges from 6 mg/l to 17 mg/l with removal efficiency ranges from 93% to 97%.

As shown in Table 5.3, the suspended solid (SS) is very low in the MBR and ASEA effluent during the whole experiment (180 samples), even though a great fluctuation was observed in the influent SS concentration. The efficiency of the removal of SS remained as high as 98% in both pilot plants. The previous literatures agrees that MBR plants always demonstrated better separation effect of the ultrafiltration membrane module in submerged membrane activated sludge system than that of the settling tank in classic activated sludge system [4], [5]. The UF/MF membrane can capture all SS in the reactor because of its fine pore size [6], [7].

Reference [19] recorded high treatment efficiency regardless of the absolute level of sludge concentration in the MBR, and unaffected by variations in SS influent concentrations.

Reference [9] concludes that the results of this comparative study indicate that in the case of MBR there is no need for further treatment, while after activated sludge additional filtration will be required.

The concentration of influent ammonia ranges from 18 mg/l to 25 mg/l. In case of MBR, The concentration of ammonia in the effluent ranges from 0.41 mg/l to 14 mg/l and the ammonia removal efficiency ranges between 44% and 98%. In case of ASEA pilot plant, the concentration of ammonia in the effluent ranges from 0.5 mg/l to 20.2 mg/l with removal efficiency ranges from 19% to 97%.

The ammonia removal efficiency is higher in MBR than in the activated sludge process at low organic loads. These results are in agreement with [20], who reported that ammonia removal efficiency ranged from 98.2 % to 99.9 % with an average value of 99.3 %, which implies that almost all ammonia nitrogen of the influent has been converted to oxidized nitrogen. Reference [16], reported that ammonia removal was recorded 99.8 %. The high removal of ammonia at the beginning of the experiment indicated that the nitrifying bacteria growth in the reactor was occurred during the two weeks acclimatization period.

At higher organic loads, the ammonia removal efficiency reaches up to 19% and 44% in case on ASEA and MBR respectively. This could be attributed to the fact that the DO in case of high organic load is utilized in the oxidation of organic matter and there was no enough oxygen for nitrification process.

According to [8], there is a decrease in nitrification rate at very low SRT (2 days), supposedly due to a partial loss of nitrifying microorganisms. On the other side, Li et al., 2006 observed a decreasing trend of nitrifiers when increasing the sludge concentration, i.e., solids retention time. Another study confirmed a negative influence of long SRT on nitrification performance, Reference [11], which was explained by impeded oxygen and substrate transfer owing to an increase in MLSS concentration.

These findings indicate that a compromise should be found between a sufficiently long SRT necessary to prevent the washout of nitrifiers, and a negative influence of too long SRT (decreased mass transfer due to poor aeration). However, over 90% removal of NH3-N is usually achieved in MBR systems, almost independent on the SRT [11], [14] investigated a performance of an MBR system which start-up was done without any sludge inoculum. As far as HRT is concerned, several studies noted a complete nitrification in an MBR operating with a HRT as low as 2 h[3].

From the results of this research, it could be concluded the following conclusions:

- The COD removal efficiency ranges from 93% from 98% in case of MBR pilot plant and ranges from 89% to 91% in case of ASEA pilot plant.
- The BOD5 removal efficiency ranges from 96% from 97% in case of MBR pilot plant and ranges from 93% to 95% in case of ASEA pilot plant.
- The SS removal efficiency ranges from 95% from 98% in case of MBR pilot plant and ranges from 93% to 97% in case of ASEA pilot plant.
- The ammonia removal efficiency ranges from 44% from 98% in case of MBR pilot plant and ranges from 19% to 97% in case of ASEA pilot plant.
- Membrane Bioreactor Technology provides a good alternative to the conventional treatment of municipal wastewater at small wastewater treatment capacities.
- The quality of the effluent from both membrane and activated sludge (extended aeration) is complying with Saudi regulations.

It is recommended to continue use of extended aeration wastewater treatment plants in Saudi Arabia for the following reasons:

- The effluent quality is complying with Saudi regulations.
- The process is reliable and simple to operate in Saudi and suitable for small and scattered communities which spread in the kingdom of Saudi Arabia.

- The extended aeration plants are used in the country since 40 years and operators in Ministry of Water and Electricity are familiar with such type of plants.
- The extended aeration plants were built in everywhere in the country under different climate conditions and give good performance and produce good effluent quality complying with Saudi regulations.

From this research it could be concluded that MBR technology can be used in Saudi Arabia due to the following reasons:

- In case of upgrading existing wastewater treatment plants or in case of three is no enough land for activated sludge (extended aeration).
- Simple process by eliminated the use of settling tanks which will save a lot of capital cost.
- In case of expansion of the existing wastewater treatment plant when the land is not available.
- In case of reuse of treated effluent in the industrial purposes in case of need high effluent quality.
- Depending upon the pore size MBR process has a capability of significantly reducing the viral and bacterial rate, which give a high effluent quality, which is considerably cheap and effective.

Gravity filtration is possible and only modest power expense is required including the suction filtration. Membrane panels can be easily and quickly installed, and maintained by ascending or descending the units along guide rails. Membrane cleaning using chemicals is normally required only twice a year.

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