

NITROGEN AND PHOSPHORUS REMOVAL FROM SALINE WASTEWATER USING UP-FLOW SLUDGE BLANKET FILTRATION PROCESS

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ABSTRACT

There is recent trend of providing additional treatment of wastewater beyond tertiary level. The purpose is to refine water to a quality that is safe for reuse for unrestricted irrigation and other non potable uses. For this purpose Kuwait has built and operated an advanced wastewater treatment plant with present capacity of 500,000 m³/d. This plant providing treatment beyond tertiary utilizes the process of ultra filtration (UF) and reverse osmosis (RO). The reject water of this unit contains high concentration of total nitrogen and total phosphate. Safe disposal of this water into the environment or possible reuse needs substantial reduction of these chemicals.

In this study, a bench scale up-flow sludge blanket filtration system was investigated to treat a synthetic saline wastewater rich in nitrogen and phosphorus compounds. The system operated with an average hydraulic-retention time (HRT) of 19 h whereas, sludge age varied within the range of 14 to 16.5 d. The results show that the average removal efficiencies of the system for biological oxygen demand (BOD), chemical oxygen demand (COD) were over 86%, and 82%, respectively. The phosphate and nitrogen average removal were found to be 50% and 45% respectively.

Keywords: wastewater, treatment, sludge, saline, nitrate, phosphate.

1. Introduction

The scarcity of water is considered as an extremely important issue to Kuwait which belongs and located in arid zones. These regions are characterized by limited rainfall, absence of fresh surface water, and limited renewable groundwater resources. During recent years economic development, high population growth, expanded urbanization and agricultural activities have placed substantial strains on the available water resources in Kuwait. The increasing imbalance between water supply and demand has compelled Kuwait to augment supplies through seawater desalination, and reuse of treated wastewater.

To achieve this goal, a pioneering advanced treatment plant with a capacity of 500,000 m³.d⁻¹ had been built and commissioned in 2004 at Sulaibiya site. The plant utilizes conventional biological processes for treating wastewater up to tertiary level. The tertiary effluent is further treated through advanced processes of ultrafiltration (UF) and reverse osmosis (RO) to produce effluent with excellent quality. The ultimate goal is to recover nearly 85% of influent wastewater as effluent/product water. The remaining portion is expected to be the reject of RO systems. It constitutes a substantial portion of the total influent. These quantities of rejected wastewater have a negative impact on receiving water and cause marine pollution. This is because salts, nitrogen and phosphorus contents are concentrated as a result of selective separation of RO membrane. The disposal or reuse of untreated RO reject wastewater has raised environmental concern. Direct disposal to water body may invigorate the growth of aquatic mass causing environmental problem. Disposing on land has potential of concentrating salts and nutrient compounds in soil and

contaminating groundwater. Hence, the RO reject water produced from the wastewater treatment needs some kind of further treatment for removing concentrated organics, particularly nutrients of N and P before safe disposal or reuse.

1.1. Biological treatment of saline wastewater

Biological activities in the activated sludge system are sensitive to environmental factors such as temperature, pH, dissolved oxygen and feed conductivity. The effect of salt on nitrification/denitrification process is a major concern in recent years. Saline wastewater are usually treated through physico-chemical means, as conventional biological treatment is known to be strongly inhibited by salt (mainly NaCl). However, physicochemical techniques are energy-consuming and their startup and running costs are high. Nowadays, alternative systems for the removal of organic matter are studied, most of them involving anaerobic or aerobic biological treatment [1]. Previous studies indicated that high salinity adversely effects the reduction of chemical oxygen demand (COD) in normal wastewater plants of activated sludge [2,3]. However, the adaptation of biomass to saline wastewater improved COD reduction [4,5]. Another study indicated that nitrogen reduction is insignificantly effected up to a salt level of 4000 mg.L⁻¹ just little above 10% of salt concentration in normal seawater. Even at this low level of salt however, phosphorus reduction dropped from normal reduction of 82% to only 25% showing severe interference of salt [6]. Concerning nitrogen, a similar study reported that in low salt concentration, ammonia reduction can be achieved within the range of 20 to 50% [7]. Past records of studies with highly saline wastewater from seafood industry and RO or other membrane processes treating wastewater effluent are inadequate to draw any conclusive inference on the treat-ability of saline wastewater. In such water, high levels of nutrients (nitrogen ranging of 50-60 mg.L⁻¹ and phosphorus ranging 10-12 mg.L⁻¹) are common features. A recent sequential batch reactor (SBR) study concentrated on nutrient reduction from saline wastewater (artificial seafood processing wastewater). The wastewater was prepared to have the approximate concentrations of total COD 1000 mg.L⁻¹, soluble COD 500 mg.L⁻¹, TKN 120 mg.L⁻¹, PO-P 20 mg.L⁻¹ [8]. In this study 80-92% organics and nitrogen reduction was reported and also found that after the influent was modified with acetate addition, satisfactory phosphorus reduction was also achieved within 2-3 d [8]. The author reported nutrient reduction efficiency in sequential bio-reactors with variable hydraulic retention time. Best removal rate was recorded at 24 h hydraulic retention and 12 days sludge age. The author reported that better result is accomplished from the acclimatization of bacteria at higher salinity as reported by others [4,5].

The Up-flow Anaerobic Sludge Blanket (UASB) reactor is considered to be one of the most successful anaerobic systems, capable of forming dense aggregates by auto immobilisation and consequently allowing high-rate reactor performance [9]. Its primary use is in the treatment of high concentration industrial wastewaters, but it can be also used in the treatment of municipal wastewater which has a lower contaminant strength [10].

2. Methodology

2.1. Experimental set-up

The bench-scale USBF reactor utilized for this study was assembled and fabricated using transparent plexiglass at KISR main workshop. The system consisted of three compartments with overall reactor volume of 37.5 l as shown in Figure 1. The compartments were anoxic, aeration and clarifier. The anoxic compartment was designed for nitrate reduction by denitrifier bacteria and phosphorus uptake by polyphosphate accumulating organisms (PAO's). The main function of the aeration compartment was nitrification and phosphorus luxury uptake [11]. The recycling sludge from the clarifier was directed to the anoxic compartment by an external pump. Required air was introduced using filtered in-house compressed air via air diffusers placed at the bottom of the aerobic compartment for microbial metabolism. The design feature of the system is listed in Table 1.

Table 1: Design feature of the USBF system.

Description	value
Number of reactor tank	1
Volume of anoxic compartment (L)	12.75
Volume of aerobic compartment (L)	24.75
Total volume of the reactor (L)	37.5
Volume of clarifier (L)	8
Depth of clarifier (m)	0.3

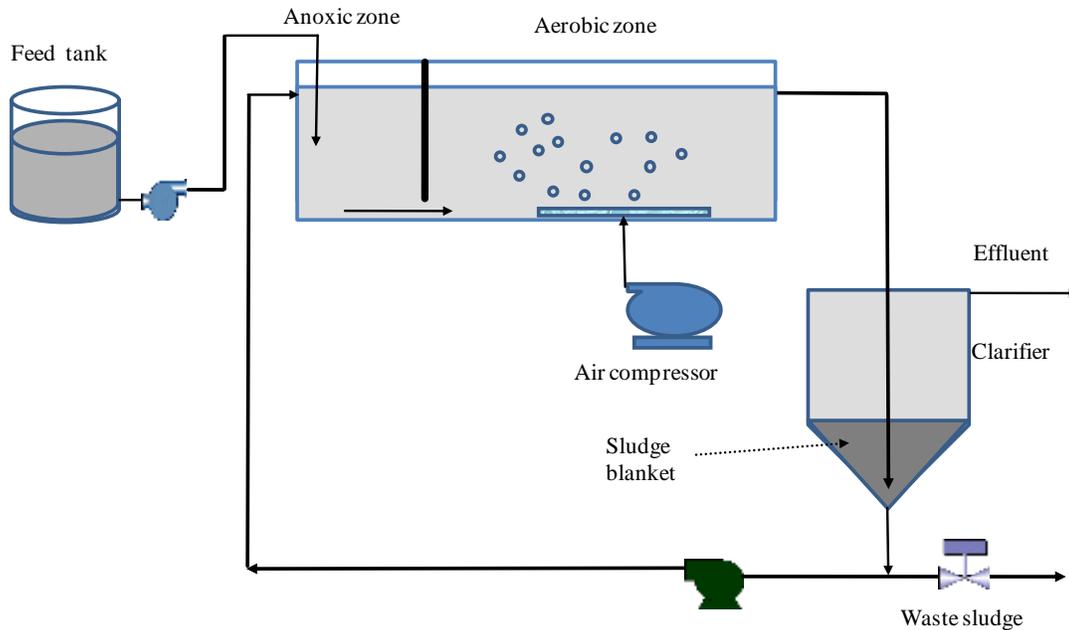


Figure 1: Schematic diagram of experimental equipment.

2.2. Synthetic wastewater

The synthetic wastewater was prepared to simulate the reverse osmosis brine produced at Sulaibiya Wastewater Treatment Plant. The required concentrations of nitrate and phosphate in synthetic wastewater were obtained by utilizing NaNO_3 and KH_2PO_4 , respectively. Carbon sources of glucose was added to maintain biological activity needed to degrade various concentrations of nitrate and phosphate [12, 13]. In order to achieve the required amount of salinity to resemble RO reject water, NaCl was added. The synthetic wastewater characteristics have been depicted in Table 2 [13].

Average composition of the synthetic wastewater was electrical conductivity = $6100 \mu\text{s}\cdot\text{cm}^{-1}$, COD = $600 \text{ mg}\cdot\text{L}^{-1}$, $\text{N}\text{-NO}_3^- = 57 \text{ mg}\cdot\text{L}^{-1}$ and $\text{P}\text{-PO}_4^- = 73 \text{ mg}\cdot\text{L}^{-1}$ throughout the study.

2.3. Process operation

Synthetic wastewater stored in 1 m^3 storage tank was pumped into the anoxic zone of the USBF bioreactor system. The influent flow rate was maintained at $2 \text{ L}\cdot\text{h}^{-1}$, resulting at a mean hydraulic retention time (HRT) of approximately 19 h. the recirculation sludge flow was maintained equal to influent flow rate. Sludge wastage was performed daily by discarding sludge from the bottom of the clarifier to achieve required sludge retention time of 15 days. The air flow adjusted to maintain dissolved oxygen (DO) at average concentration of $2.5 \text{ mg}\cdot\text{L}^{-1}$ in the aerobic zone for efficient

nitrification process, while the DO levels in the anoxic zone was practically zero. Temperature and pH were controlled within the range of 22 to 23°C and 6.3 to 8.7, respectively.

2.4. Analytical method

The system was operated for about 3 months and runs of steady state data were collected. Steady state conditions were assumed to be achieved when the most recent three measurements of chemical oxygen demand (COD) and nutrient (nitrogen and phosphorus) concentrations were within 10%. Samples were collected from influent, effluent and sampling port of the system. Daily measurements of conductivity, temperature, pH and DO were taken before sampling. Laboratory tests for water quality parameters were conducted in the laboratory at the Sulaihiya Wastewater Research Plant. Test results were cross-checked with results obtained at the MPW laboratory at the Data Monitoring Center (DMC). Main parameters measured were temperature, pH, TSS, VSS, settleable solids, COD, BOD, conductivity, TDS, sulphate, TN, PO₄, chloride, NH₄-N, alkalinity as CaCO₃, and NO₃-N. Laboratory analysis was performed according to Standard methods for the examination of water and wastewater [14].

Table 2: Composition of synthetic wastewater used in this study.

Parameter	Concentration (mg.L ⁻¹)
C ₆ H ₁₂ O ₆ -H ₂ O	56-400
K ₂ HPO ₄	84
(NH ₄) ₂ SO ₄	235
NaHCO ₃	500
MgSO ₄ .7H ₂ O	100
CaCl ₂	50
FeSO ₄ .7H ₂ O	1
NaNO ₃	31-223
KH ₂ PO ₄	14.5-86
NaCl	300
KCl	20

3. Analysis

3.1. COD removal from saline wastewater

The influent concentration of COD was highly fluctuating and was in the range of from 240-880 mg.L⁻¹ with an average value of 576 mg.L⁻¹. Whereas the average COD concentration in the effluent was 99 mg.L⁻¹. Figure 3 shows the COD of influent, effluent and the percentage of COD removal. As can be seen in Figure 3, there were significant reductions in COD values with an average removal efficiency of 82%. This revealed the heterotrophic bacteria which is responsible of degrading the carbonaceous organic were rich in aerobic zone of the system. Results obtained in this study shows that the COD removal efficiency from saline wastewater is in agreement with previous studies been published [15,16, 17].

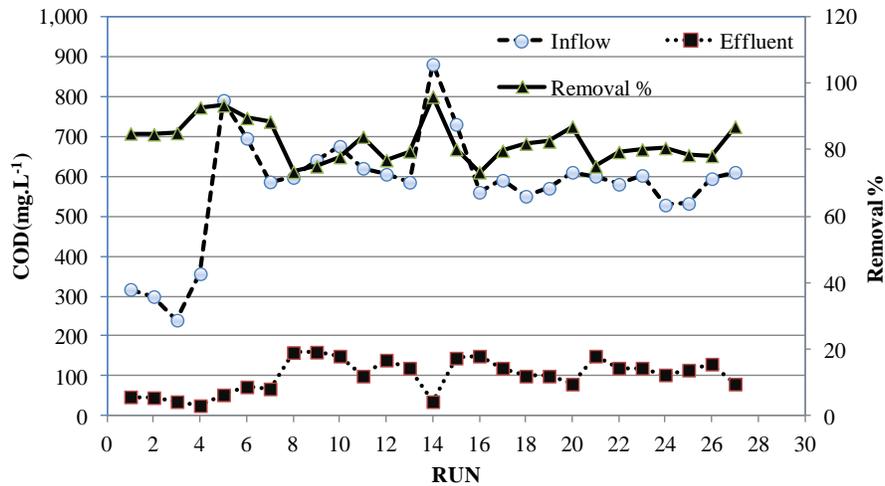


Figure 2: Variation of influent, effluent and removal efficiency of COD.

3.2. Nitrogen removal

Nitrification is the main process in removing total nitrogen from the wastewater and this removal is occurred in two step processes: nitrification followed by denitrification. The nitrate concentration in this study varied between 11mg.L⁻¹ to 39 mg.L⁻¹ and the average value was 23.1 mg.L⁻¹. Figure 3 presents NO₃⁻ removal efficiency for all steady state runs. It is noted that the percentage removal was ranged from 42.2% to 74.3% with an average value of 59.7%. This average removal of nitrate indicates that the nitrification/denitrification process was incomplete. Many researchers have reported similar results and they concluded that both salinity and COD are found to be inhibitors of nitrification [18]. Furthermore, incomplete nitrogen removal in this study may be due to low concentration of mixed liquor suspended solids (MLSS) in the reactors. This occurred because of sludge circulation to the anoxic tank was started at beginning of the experiment and therefore the time for denitrifying bacteria growth was limited. The same observation is also reported by previous study [19]. Therefore more time is needed to accumulate denitrifying bacteria in the acclimatization period. In addition, poor nitrate removal might be occurred because of insufficient DO concentration (2.5 mg.L⁻¹) in the aeration tank. Similar results were also observed by many researchers investigating nitrification process in wastewater treatment systems. They found that to ensure complete nitrification the DO in the aeration tank need to be maintained around 3.5 mg.L⁻¹ [20].

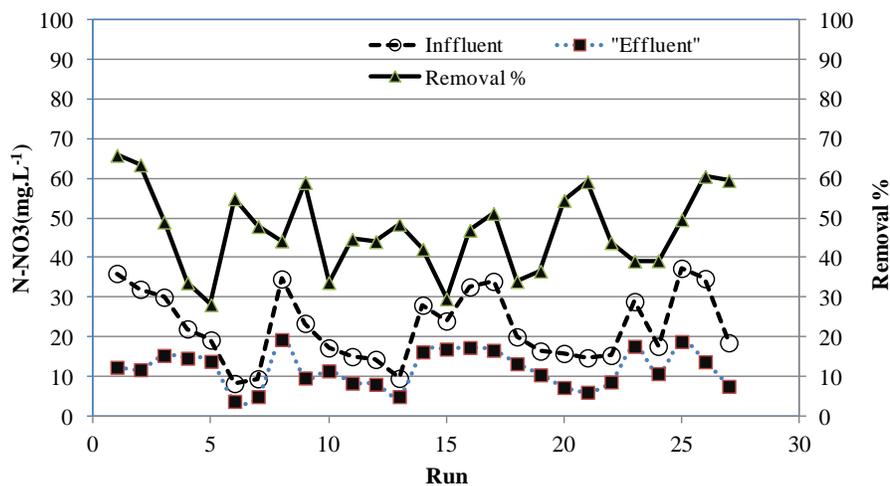


Figure 3: Variation of influent, effluent and removal efficiency of NO₃.

3.3. Phosphorus removal

Biological P removal using sequential anoxic/aerobic bioreactors system was carried out in this study. In the biological phosphorus removal, the phosphorus in the influent wastewater is incorporated into cell biomass, which subsequently is removed from the process as a result of sludge wasting [21]. Figures 4 depict the variation of P-PO₄ concentration for the influent, effluent and percentage removal of phosphate occurred in the system. The influent P-PO₄ was fluctuating during the period of operation between 3 and 22 mg.L⁻¹ with an average value of 12.1 mg.L⁻¹. P-PO₄ concentration in the effluent was varied from 1.3-12.3 mg.L⁻¹ with an average value of 6.2 mg.L⁻¹. Phosphate removal was ranged between 38.2 and 63.5% with an average value of 49.6%. This restively poor elimination of phosphate is expected in this type of conventional processes. The incomplete phosphorus removal may resulted from carbon substrate competition between phosphorus accumulating organisms (PAOs) and the denitrifying bacteria. Excess carbon substrate in the system is crucial to successful removal for both nitrate and phosphate. Biological phosphorus removal is initiated in the anaerobic reactor where external carbon source is taken up by PAOs and converted to carbon storage products that provide energy and growth in the anoxic and aerobic reactors. Similar observation were reported by many researchers investigating biological nutrients removal process in wastewater treatment systems [22].

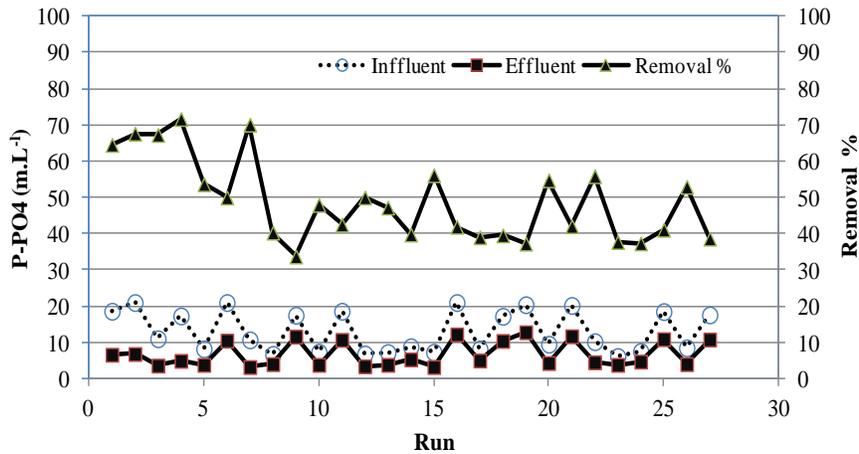


Figure 4: Variation of influent, effluent and removal efficiency of P-PO₄.

4. Conclusion

In this study a laboratory-scale system was developed to biologically treat synthetic saline wastewater. The results of this study demonstrated high removal efficiency was achieved for COD with an average removal efficiency of 83%. The results showed that the tested system was capable of handling impact of high organic load. The average removal efficiencies of N-NO₃, P-PO₄ were 59.7% and 49.6%, respectively. Although the nitrogen and phosphorus removal was not very high, it could be improved by modifying operating conditions such as increasing concentration of MLSS, DO and carbon source. The system can be used for the treatment of high salinity waste water with high organic load.

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