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Removal of odorous compounds from hospital wastewater

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ABSTRACT

A study was carried out to assess the removal efficiency of odorous compounds from the wastewater of hospitals in Kuwait using aeration with activated sludge technique. Samples were collected from the outlet of wastewater from Maternity Hospital. The collected samples were transferred to the laboratory of Sulaibiya Research Plant (SRP) of KISR. Each sample was divided into three parts: the first part of the sample was analyzed to obtain characteristic of hospital wastewater, while the second and third samples were mixed with activated sludge from Kabd wastewater treatment plant and underwent aerobic treatment for 12 and 24 h periods in two bioreactors using a different intensity of aeration. In the first bioreactor, the dissolved oxygen (DO) was kept on the level of 2 mg/L, while in the second 4 mg/L. Wastewater and effluents samples were analyzed for the examination of the following parameters: temperature, pH, electrical conductivity, chemical oxygen demand (COD), ammonium, nitrite, nitrate, organic nitrogen, total nitrogen (TN) and sulfides. Based on obtained results of analyses, the removal efficiency of wastewater parameters were calculated mainly for COD, NH_4–N, sulfides and TN. The laboratory results indicated that after a hydraulic retention time (HRT) of 24 h, the mean values of sulfide removal efficiency increased from 82.54% to 93.85%, when DO increased from 2 to 4 mg/L, respectively. Under the same previous operating conditions, the mean value of ammonium removal efficiency was increased from 85.96% to 97.44%. To obtain the best effluents the biological process should be extended aeration type with HRT 24 h at DO 4 mg/L. The obtained results will be recommended as the base for treating wastewater from hospitals in package units before discharging to sewage network.

Keywords: Dissolved oxygen; aeration, ammonium, sulfides and wastewater

1. Introduction

Sulaibikhat Bay in Kuwait suffers from water pollution due to the discharge of sewage to the bay. There is suspicion that the part of incoming sewage belongs to nearby hospitals, so it was decided to check the wastewater from Maternity Hospital and its treatability in the process of aeration with activated sludge method. The most convenient way to solve the problem is to install package units to treat the sewage from hospitals on site. In Kuwait, Al-Haddad et al., 2014 studied the removal of hydrogen sulfide from groundwater by an aeration technique. The goal of the project presented was to find out how much aerobic activated sludge can reduce the concentration of pollutants responsible for odor as well as other organic pollutants, which can be treated by microbiological processes. In Kuwait, all of the hospital wastewater is treated in municipal sewage treatment plants. Hospital wastewater flows by gravity to the nearest wastewater pumping station and is pumped to wastewater treatment plant afterwards. The oxidation of odorous compound as ammonium and sulfides can be done in biological way. For ammonia, there is a reaction called nitrification. Two types of bacteria are responsible for nitrification: nitrosomonas and nitrobacteria. Nitrosomonas bacteria oxidize ammonia to nitrite product (Metcalf & Eddy, 2003). Nitrite is afterwards converted to nitrate by nitrobacter. Approximate equations for these reactions can be expressed as follows:

$$55NH_4^+ + 76O_2 + 109HCO_3^- \rightarrow C_5H_7O_2N + 54NO_2^- + 57H_2O + 104H_2CO_3 \quad (1)$$

$$400NO_2^- + NH_4^+ + 4H_2CO_3 + HCO_3^- + 195O_2 \rightarrow C_5H_7O_2N + 3H_2O + 400NO_3^- \quad (2)$$

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Hydrogen sulfide as a main case of sulfides can be biologically oxidized to sulfuric acid as follows:

$$H_2S + 2O_2 + \text{bacteria} \rightarrow H_2SO_4 \quad (3)$$

The hospital wastewater in Kuwait is treated only in municipal wastewater treatment plants but the effluents obtained contain residues of pharmaceuticals (Carballa et al., 2004; Kolpin et al., 2002; Kummerer 2001 and Snyder et al., 2003). Efficiency of hospital wastewater treatment were investigated all over the world (Amouei et al., 2012; Alrhmoun et al., 2014; Beirer et al., 2012; Mohammed and Al-Rassul Ali, 2012; Kootenaei and Rad, 2013; Kovalova et al., 2012; Mesdaghinia et al., 2009; Prayitno et al., 2014; Prayitno et al., 2013; Spinova et al., 2013; Su et al., 2015 and Razaee et al., 2005). From their works, there is confirmation that conventional wastewater treatment systems usually do not have the satisfactory efficiency and researchers indicate necessity of pretreatment of such healthcare institutions' effluent before discharging to municipal plants. Su et al. (2015) indicates advantage of rotating biological contractor over conventional methods. Beier et al. (2012) have found many advantages of membrane bioreactor technology for treatment of hospital and healthcare institutions' wastewater. In the frame of this project, activated sludge method will be studied as most economical among existing methods. Wiest et al., 2017 carried out the study of specific hospital wastewater treatment for two years confirming that pharmaceuticals are not completely removed by conventional activated sludge method and they recommended separate treatment of such wastewater preferably on-site of hospitals. Tuc et al., 2016 investigated how antibiotics are treated in wastewater treatment plants and how they behave in sewage network. They found that a major part of antibiotics is not treated and they flow out with effluents. Verlicchi et al., 2012 investigated distribution and concentration of pharmaceuticals in hospital effluents. The authors indicated that municipal wastewater treatment plants have significant amount of antibiotics in their effluents. According to Kummerer, 2001, in wastewater treatment plant effluent the concentration of antibiotics is usually 50 μg/L. In accordance with above the output of antibiotics in product water of Sulaibiya wastewater treatment and reclamation plant is around 7.3 kg/year. It is significant amount of antibiotics in product water, which is applied for irrigation purposes all over the Kuwait. The parameters discussed of hospital wastewater are not acceptable for discharging to the sea in accordance with KEPA requirements, so such wastewater have to be treated in biological method of activated sludge by aerobic technique.

2. Materials and Methods

Before starting experiments two bioreactors of organic glass (plexi-glass) were constructed in KISR's workshop. To deliver oxygen for aeration process, the laboratory scale compressor was applied (model Condor MDR2/11 bars from Peak Scientific Company).

For ensuring bubbling of air in mixed liquor special air stones were applied (fine bubble diffusers). Bioreactors were placed on special stands only to allow emptying them in an easy way. Samples were taken from wastewater outlet (manhole) from Maternity Hospital in Kuwait on a weekly basis. The installation of aerobic bioreactors is presented in plate 1.

2.1. Plate 1. bioreactors for aerobic treatment of wastewater

The sampling was carried out according to the standard operation procedure, which was in accordance with standard methods for water and wastewater examination (APHA, 2012). Sampling was carried out manually using a cylinder made of steel with volume of 6 L which was hold by a rope (10 m long). Samples for laboratory analyses were collected into glass bottles. Beside a manhole, the following field tests were carried out: temperature, conductivity, pH and dissolved oxygen (DO). Moreover multi-gas detector delivered data for impurities of ambient air above wastewater as follow: hydrogen sulfide, methane, carbon dioxide and oxygen. Total volume of samples (20 L) were collected and divided to 2 L samples, which was taken for laboratory analysis to get characterization of tested wastewater and the remaining 18 L of sample was divided into two sets of samples which were placed in two bioreactors and were mixed with the same volume of activated sludge from Kabd wastewater treatment plant. Obtained mixed liquors were aerated with two different levels of DO; the first reactor was tested for DO level as 2 mg/L while in the second one, the DO was 4 mg/L.

Aeration was done in two steps for 12 and 24 h, so the results were obtained for two periods of aeration to determinate which hydraulic retention time (HRT) is better for a discussed process. For fresh samples of wastewater and for samples of effluent after 12 and 24 h of aeration, the following analyses were carried out: temperature, pH, chemical oxygen demand (COD), DO, electrical conductivity (EC), sulfides, NH_4^+–N, organic nitrogen, nitrate, nitrite and total nitrogen (TN). For collected samples and activated sludge as well as mixed liquor total volatile solids were examined. All analyses were carried out in accordance with standard methods for water and wastewater examination (APHA, 2012).

3. Results and discussion

All of the results were collected in spreadsheet. The pH value of the collected raw wastewater from Maternity Hospital ranged between 5.94 and 7.50, with mean value of 6.80. These data indicated a slight acidic wastewater environment. On the same manner, the DO value ranged between 0.42 and 3.35 mg/L, with mean value of 1.17 mg/L. The collected wastewater of manhole revealed a low oxidized environment. EC of raw wastewater was ranged from 551 to 941 μS/cm, with the mean value 710 μS/cm. In general, the raw wastewater was characterized by slightly acidic, reduced environment of freshwater source.

The collected samples also showed high COD values which ranged between 400 and 750 mg/L, with a mean value of 633.28 mg/L. The quality of raw wastewater with respect to COD values was in agreement with of Iranian wastewater tested by Amouei et al, 2012. The minimum, mean and maximum values of NH_4–N were found to be 11.3, 20.64 and

38.90 mg/L, respectively. On the other hand, the maximum value of TN reached 188 mg/L, while its minimum value was 26 mg/L, (mean value of 65.06 mg/L). In general the NH_4–N is the main odor compound contained in raw wastewater. Notice that the mean concentration of TN was found to contain mainly (95%) of organic nitrogen and ammonium nitrogen.

The sulfide gas concentration of raw wastewater was ranged between 0.015 and 0.796 mg/L with mean value of 0.105 mg/L. The relatively high values of sulfide were observed only in a sampling dated 24 January 2017. In general, these values indicated a low decomposition of organic matter producing sulfides and hydrogen sulfide. Moreover, the sulfide gas concentration was significantly lower than ammonium gas concentration in raw wastewater.

The laboratory results of NH_4–N in raw wastewater and effluents for hospital samples exposed to 12 h aeration at DO 2 mg/L were plotted in Figs. 1 and 2. This set of experiment was planned to fix the DO at 2 mg/L, however, it was difficult to control the level of DO at the bioreactor. Therefore, the mean value of DO was found to be 3.06 mg/L. The chosen DO levels of experiment were in agreement with practical industrial values applied in wastewater treatment plants in Kuwait (set points for DO are in the range from 3.0 to 4.0 mg/L).

3.1. Changes of ammonium concentration in raw wastewater and effluent after 12 and 24 h of aeration at DO 2 and 4 mg/L

The NH_4–N concentration in effluent ranged between 0.0 and 32.95 mg/L, with mean value 10.48 mg/L for the first option of parameters (HRT 12 h at 3.21 mg/L as mean value for DO). The NH_4–N removal efficiency ranged between 11.74% and 100%, with a mean value at 66.08 mg/L (Table 1). It should be also highlighted that the first experiment was carried out as a blind, with the absence of activated sludge. Therefore, the obtained results for efficiency represent only effect of aeration process without the standard biological treatment. Regarding the second set of experiment which was carried out at HRT 24 h and DO 2 mg/L, the results were presented in Fig. 1. Moreover, the ammonium of the effluent was found in the range from 0.00 to 14.85 mg/L, with a mean value of 3.29 mg/L. The minimum, maximum and mean value of the removal efficiencies were found as 85.96%, 100% and 76.53% respectively.

In the third set of experiments, DO was fixed for 4 mg/L and HRT 12 h. Ammonium concentration in effluent ranged from 0 to 27 mg/L with a mean value of 6.42 mg/L (Fig. 2). The removal efficiency values were ranged from 9.85% to 100% with a mean value of 76.53%. In general, the ammonium concentration in the effluent (6.48 mg/L) was lower than the value (16 mg/L) set by KEPA (2001) for irrigation purposes.

In experiments with DO 4 mg/L and HRT 24 h, the ammonium removal was the best; it ranged between 77.88% and 100%, with the mean value 97.44% (Fig. 2). Moreover for this case, the concentration of ammonium in effluent was ranged from 0 to 23.1 mg/L, with a mean value of only 2.24 mg/L (Fig. 2 and Table 1). The improvement of NH_4–N in concentration of an effluent was due to the nitrification processes (Eqs. (1) and (2)).

3.2. Concentration of sulfides in raw wastewater and effluents after 12 and 24 h of aeration at DO 2 and 4 mg/L

The concentrations of sulfides in an effluent after activated sludge process were very low, and thus it can be considered that they are efficiently removed. The changes of sulfides concentration were presented in Fig. 3 and Table 2), which show a low concentration of sulfides in both the cases when DO was at 2 and 4 mg/L. The mean, maximum and minimum values for the sulfides concentration in raw

Plate 1. Bioreactors for aerobic treatment of wastewater.

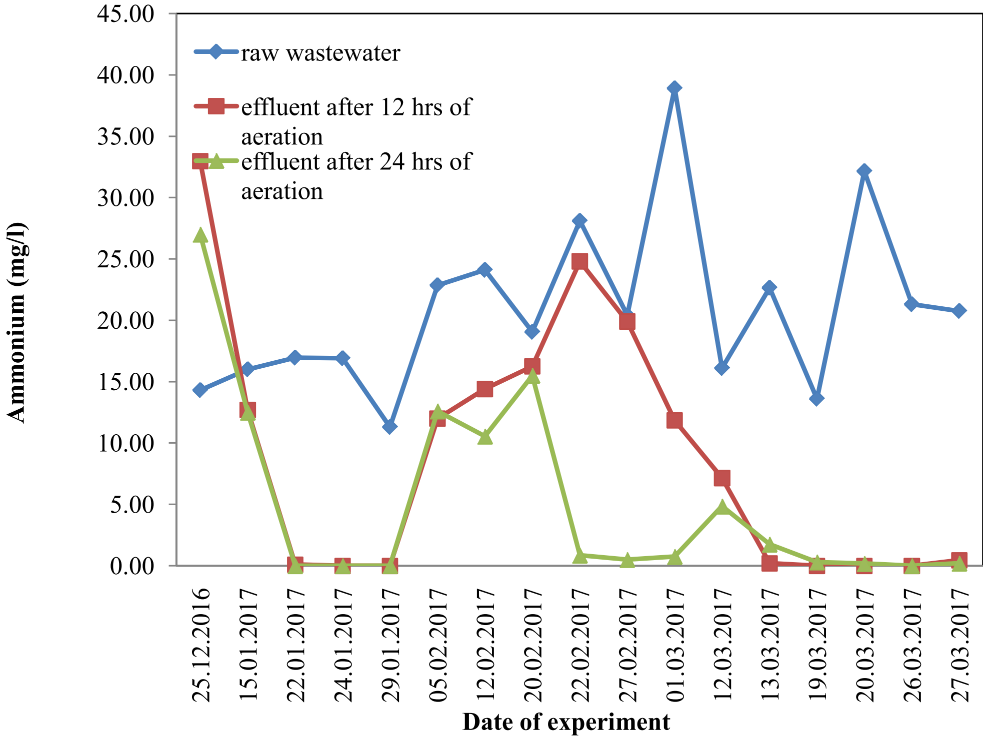

Fig. 1. Ammonium in wastewater and effluents after 12 and 24 h of aeration at DO 2 mg/L.

Table 1
Statistical analysis of NH_4–N concentration in raw wastewater and effluents after 12 and 24 h of aeration at DO 2 and 4 mg/L

	Raw wastewater	12 h @ 2 mg/L DO	12 h @ 4 mg/L DO	24 h @ 2 mg/L DO	24 h @ 4 mg/L DO
Range	9.45–38.9	0–32.95	0–27	0–14.85	0–23.1
Mean	19.98	9.43	6.48	3.29	2.24
STD	7.2	9.8	8.5	4.9	5.8
CV (%)	36	103	131	148	259
% Mean removal efficiency	–	66.08	85.96	76.53	97.44

DO = dissolved oxygen; STD = standard deviation; CV = coefficient of variation.

wastewater was found as 0.105, 0.796 and 0.015 mg/L respectively (Table 2). There were little differences between sulfides concentration in effluents for HRT 12 h, (0.016 mg/L) and HRT 24 h (0.009 mg/L). For the first option of parameters (HRT 12h at DO 2 mg/L), the sulfides concentration ranged between 0.000 and 0.109 mg/L, with a mean value of 0.016 mg/L (Fig. 3, Table 2). The removal efficiency for this option ranged from 32.04% to 100%, with the mean value of 76.76% (Table 2).

For the second option of process parameters (HRT 24 h at DO 2 mg/L), the concentration of sulfides in effluent ranged from 0.000 to 0.058 mg/L, with mean value 0.009 mg/L and removal efficiency was from 40.78% to 100 mg/L, with mean value of 83.64% (Table 2, Fig. 3). In third options of parameters (HRT 12 h at DO 4 mg/L), the sulfides concentrations were ranged from 0.000 to 0.061 mg/L, with a mean value of 0,011 mg/L. The removal efficiency ranged from 43.69% to 100%, with mean value was 82.54%. The improvement in the sulfide concentrations in discussed effluents was due to the oxidation of sulfides to sulfates (Eq. (3)).

For fourth option (HRT 24 h at DO 4 mg/L), sulfides concentration were ranged from 0.000 to 0.057 mg/L, with mean value was 0.006 mg/L. The removal efficiency ranged from 72.73% to 100%, while mean value of 93.85%. It was found that an increment HRT from 12 to 24 h improved removal efficiency by 10% (Table 2).

3.3. Changes of COD for wastewater and effluents after 12 and 24 h of aeration at DO 2 and 4 mg/L

The COD values for raw wastewater ranged from 400 to 750 mg/L with a mean value of 633.28 mg/L. As shown in Figs. 4 and 5, the COD was reduced in significant way.

Table 2
Statistical analysis of sulfides concentration in raw wastewater and effluents after 12 and 24 h of aeration at DO 2 and 4 mg/L

	Raw wastewater	12 h @ 2 mg/L DO	12 h @ 4 mg/L DO	24 h @ 2 mg/L DO	24 h @ 4 mg/L DO
Range (mg/L)	0.015–0.796	0–0.109	0–0.061	0–0.058	0–0.057
Mean (mg/L)	0.105	0.016	0.011	0.009	0.006
STD (-)	0.2	0.03	0.02	0.02	0.01
CV (%)	200	150	200	200	100
Mean removal efficiency (%)	–	76.76	82.54	83.64	93.85

DO = dissolved oxygen; STD = standard deviation; CV = coefficient of variation.

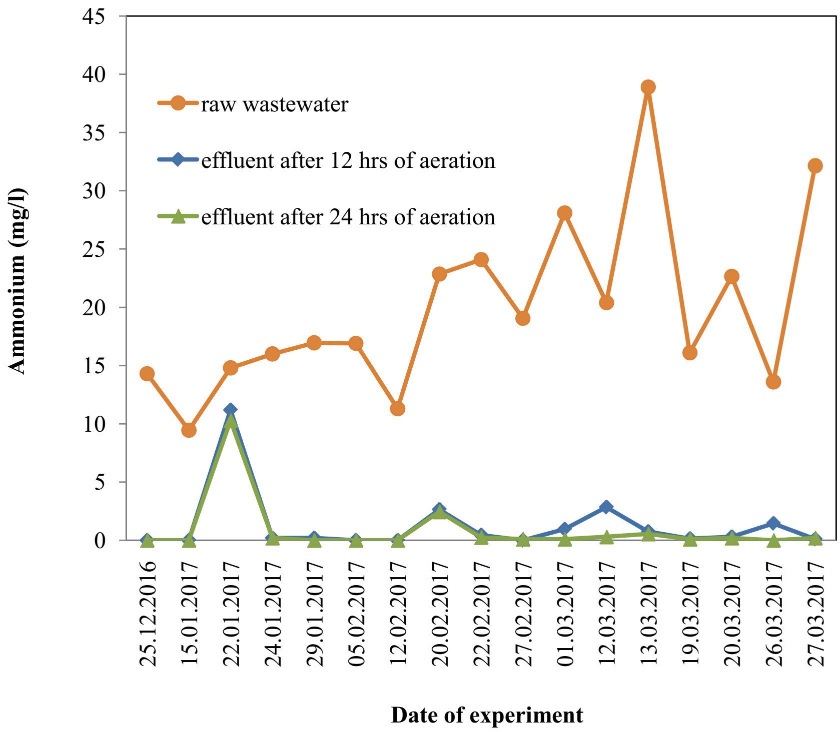

Fig. 2. Ammonium in wastewater and effluents after 12 and 24 h of aeration at DO 4 mg/L.

For an effluent after 12 h aeration at DO 2 mg/L, the mean value was found to be 59.06 mg/L (Fig. 4). The removal efficiency for this option of parameters ranged from 76.41% to 97.47%, while mean value of 93.03%.

For the second option (DO 2 mg/L, HRT 24 h), the COD mean value ranged from 15 to 139 mg/L, with the mean value of 30.7 mg/L. The removal efficiency for this case ranged from 72.89% to 97.87%, with a mean value of 93.97%. At the third set of conditions (DO 4 mg/L at HRT 12 h), the mean value was 51.93 mg/L (Fig. 5). Removal efficiency for the same parameters ranged from 75.53% and 97.73%, with a mean value of 94.67%.

For the fourth option of process conditions (HRT 24 h at DO 4 mg/L), the mean COD value was 29.31 mg/L (Fig. 5), while the minimum and maximum values were between 11 and 174 mg/L respectively. The removal efficiency for the last group of parameters ranged from 69.37% to 98.13%, with a mean value of 95.02%. These results indicated that the effluent can be used safely for irrigation purposes, if only COD values were considered.

3.4. Removal efficiency of pollutants in wastewater after aeration

The obtained results were analyzed to evaluate the effectiveness of pollutant removal. All of the results were statistically evaluated and they were presented in graphs and tables. Moreover, the efficiency was calculated for basic parameters using the following formula:

$$\text{Efficiency} = \frac{C_{\text{raw ww}} - C_{\text{effl.}}}{C_{\text{raw ww}}} \times 100\% \tag{4}$$

Where:

$C_{\text{raw ww}}$ = concentration in raw wastewater in mg/L,
$C_{\text{effl.}}$ = concentration in effluent in mg/L.

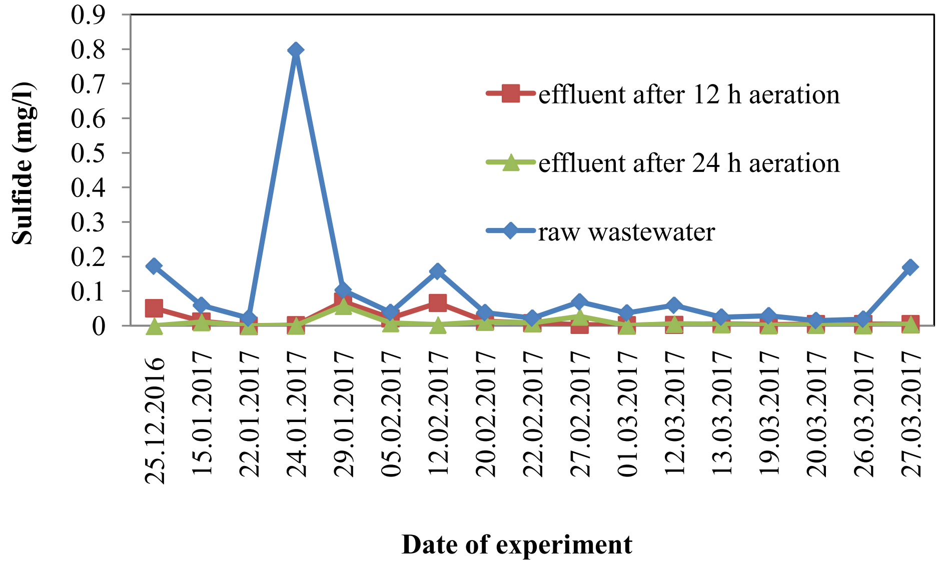

Fig. 3. Sulfides in wastewater and effluents after 12 and 24 h of aeration at DO 2 mg/L.

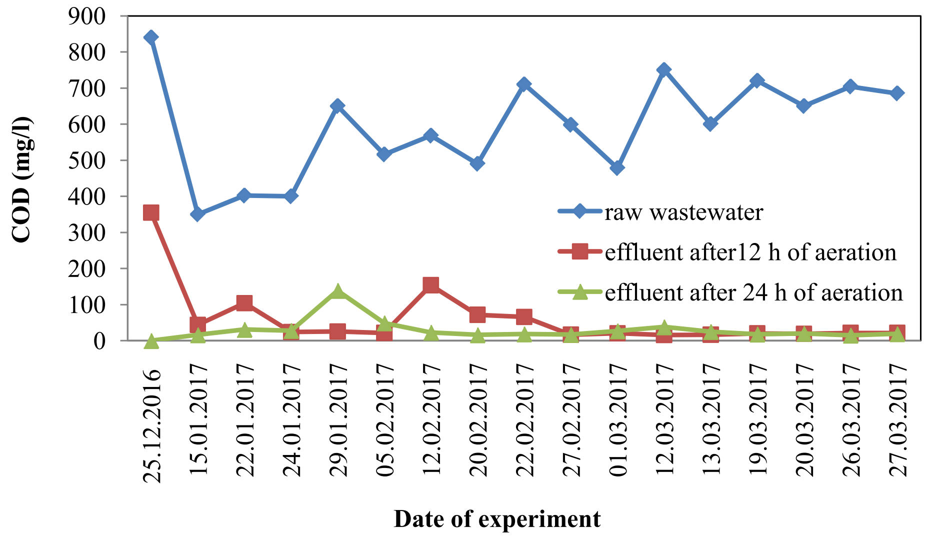

Fig. 4. COD in wastewater and effluents after 12 and 24 h of aeration at DO 2 mg/L.

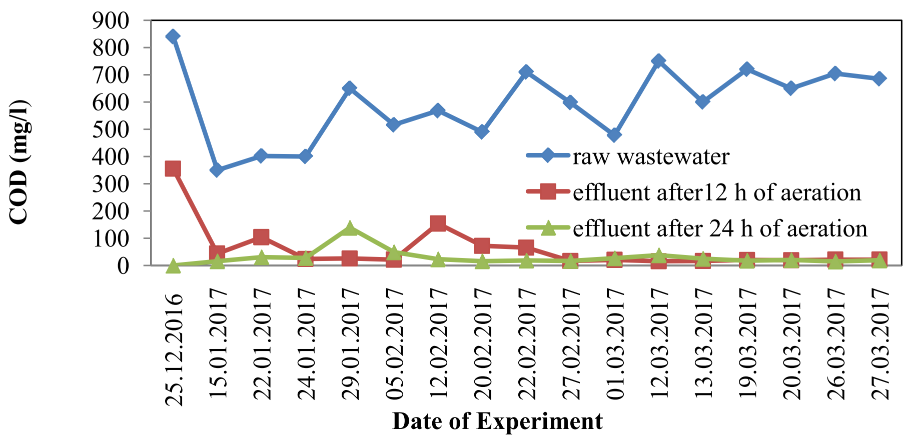

Fig. 5. COD in wastewater and effluents after 12 and 24 h of aeration at DO 4 mg/L.

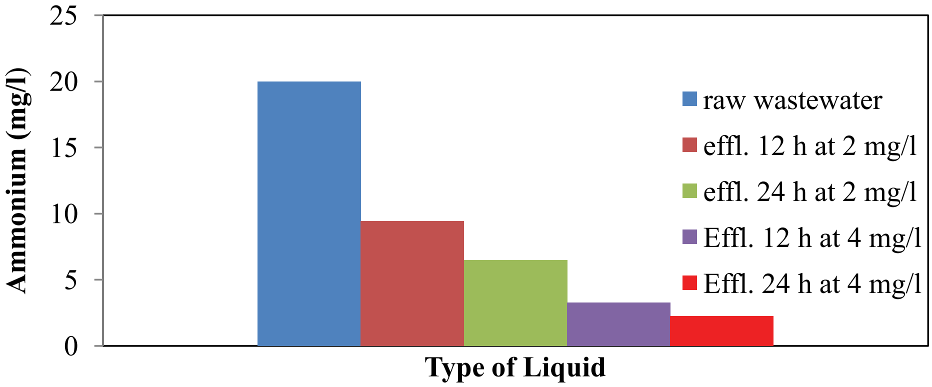

Fig. 6. Mean concentrations of NH_4–N in raw wastewater and effluents after 12 and 24 h of aeration at DO 2 and 4 mg/L.

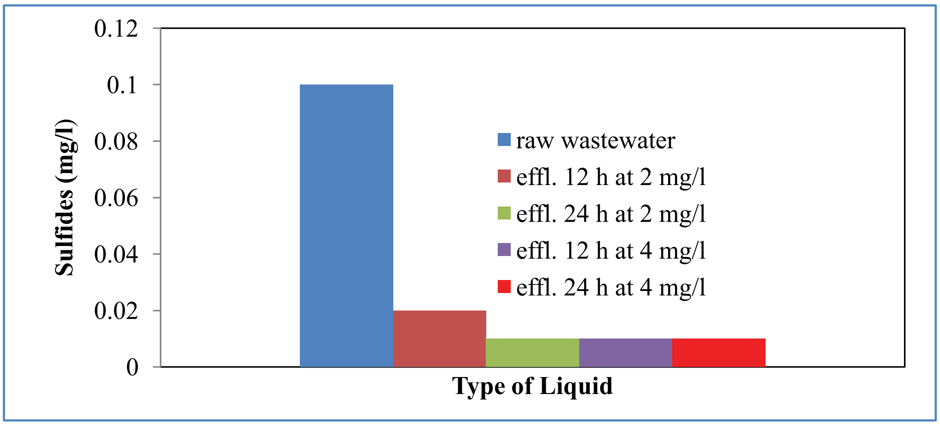

Fig. 7. Mean concentrations of sulfides in wastewater and effluents after 12 and 24 h of aeration at DO 2 and 4 mg/L.

KEPA requirements for maximum COD of irrigation water is 100 mg/L. Therefore, the obtained effluents are of acceptable values (effluent COD 29.31 mg/L and removal efficiency for HRT 24 h at DO 4 mg/L was 95.02% as mean value). It should be highlighted, that the obtained effluents for the discussed experiments had much lower COD values than KEPA (2001) effluent water standards in Kuwait.

3.5. Statistical analysis for ammonium results

As it is presented in Fig. 6 and Table 1, the mean removal of ammonium was fully satisfactory and its mean removal efficiency was found above 97% for the case of aeration for 24 h at DO for 4 mg/L. The standard deviation and variation coefficients are shown in Table 1.

3.6. Statistical analysis for sulfides results

The sulfides results were changed significantly to the value of 0.01 mg/L and removal efficiency was reached 93.85% (HRT 24 h and DO 4 mg/L). The results support the decision for HRT 24 h and DO 4 mg/L due to fact that removal efficiency for the case with HRT 12 h and DO 2 mg/L was only 76.76% (Table 2 and Fig. 7).

The obtained results for ammonium and sulfides removal were better than the results reported in previous studies. In the current study, the ammonium was removed with mean removal efficiency 97.44%, and sulfides with 93.85% (Kootenaei and Rad, 2013 reported that the mean removal efficiency values for ammonium and sulfides were ranged 88% and 79% respectively). These obtained in discussed experiments values lead to the statement that removal of odorous compounds was fully satisfactory. Amouei et al., 2012 reported mean removal efficiency for COD as 76% while the obtained results from the current study was 95.02%. Moreover the quality of effluent with respect to NH_4–N and sulfide, all met KEPA (2001) standards for irrigation purposes.

4. Conclusions

The output results of this study can be summarized as follows:

- Mean removal efficiency for ammonium nitrogen reached 97.44%.
- Sulfides, these mean values exceed 83% for 12 h of aeration and 93% for 24 h aeration if DO was fixed for 4 mg/L.

- Mean removal efficiency for COD was above 97%.
- Obtained results of parameters: NH_4–N, sulfide and COD, all met KEPA standards for irrigation water in Kuwait.

The study recommended the following:

- Construction of an onsite treatment unit near the Maternity hospital with capacity of 1,200 m^3 for operation condition of DO at 4 mg/L and HRT should be 24 h.
- Performance of bioreactor can be evaluated for extra wastewater parameters such as: antibiotics, pharmaceuticals, microbes (bacteria and viruses).
- Periodic monitoring of wastewater parameters before and after treatment should be carried out on a daily, monthly and yearly basis.

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