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Influence of aerators installation angles on process performance of an activated sludge in a full scale wastewater treatment plant, Kermanshah, Iran

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ABSTRACT

Biological reactors are the most energy-consuming facilities of conventional wastewater treatment plant (WWTP). Therefore, adjustment of aerators installation angles inside the aeration tank seems to be an effective way to ensure efficient biological performance. In this work, the biological treatment performance of Kermanshah's municipal WWTP (Kermanshah, Iran) was surveyed via varying angles of the aerators installation relative to the perpendicular. Two different aeration configurations in terms of installation angles of aerators, 30° and 45°, were considered. Effect of the aerators installation angles on variations of some operating and process parameters such as dissolved oxygen (DO), oxidation reduction potential (ORP), nitrogenous compounds, and phosphorus were pursued. From results, more DO and ORP amounts were found at the 30° angle compared to the 45° angle. However, changes trends in the DO and ORP amounts were similar at both angles. As the main conclusion, no prominent effect on remediation of carbon, nitrogenous compounds, and phosphorus was reported in these two angles. These results were justified by low influent organic loading, and also not to have appropriate conditions for nitrogen and phosphorus removal. In addition, in this study kinetic evaluation was conducted, and obtained findings were in a good agreement with literature.

Keywords: Biological treatment; Activated sludge process; Aeration system; Installation angle of aerators

1. Introduction

Various treatment processes such as biological systems [1–4], photocatalytic process [5], coagulation and flocculation technique [6–8], surface adsorption [9], and membrane filtration [10–12] have been employed to eliminate contaminants from various wastewaters. In addition to the mechanical treatment systems, natural treatment processes have been also used as a cost-effective solution for wastewater treatment. Volume yield in the natural treatment processes is comparatively low due to weak energy dissipation [13,14]. Since last decades, conventional activated sludge (CAS) as a successful biological treatment system has been operating in many wastewater treatment plants (WWTPs) around the world to treat various wastewaters. One of the most commonly used configurations of

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biological reactor in a large scale is plug-flow owing to its simplicity and robustness. In short, this technology consists of three principal parts, that is, preliminary treatment, secondary treatment, and settling process. Among these parts, the secondary treatment plays a main role in the CAS via consuming oxygen. Generally, oxygen transfer is crucial over the secondary treatment process to provide enough oxygen for microbial degradation and nutrient removal [15]. Oxygen mass transport is obtained using the aeration system. Accordingly, aerators are well-known as essential elements in the WWTPs to supply oxygen demand and adequate mixing in the aeration tank. In this regard, there are a variety of aerators including vertical pump, pump-sprayer, cascade, paddle wheel aerators based on splashing aeration, diffused-air systems, and propeller-aspirator-pumps based on bubbling aeration [16]. From economic point of view, the propeller-aspirator-pumps are the most frequently used aerators. However, the operational cost of the CAS is fairly high related to energy consumption by the aeration system ranging from 45% to 75% of plant energy expenditure [17]. Hence, the aeration process as the core of the secondary treatment has attracted much attention from WWTPs' owners. Study of the aeration system can be considered as an effective solution to achieve optimum performance of energy consumption [18]. Based on literature reports, the employment of intermittent aeration strategy based on accurate on/off cycles to set intensity and length of aeration can be convenient to mitigate a considerable portion of energy expenses and improve process performance [18,19]. In other researches, the effect of the positional angle of aerators, and also, the arrangement of air diffusers were investigated [16,18].

Kumar et al. [16] studied the effect of various geometric conditions in terms of positional angle of the propeller shaft, ranged in four levels of 30°, 45°, 60°, and 75°, on aeration efficiency of a propeller-aspirator-pump aerator. From the results, the maximum aeration efficiency was found at the positional angle of 75°. In a study of Gil-Pulido et al. [20], the effect of various aeration rates; 0.8, 0.6, and 0.4 L/min; was investigated on co-remediation of chemical oxygen demand (COD) and nutrients in an intermittently aerated bioreactor [20]. The authors reported the aeration at 0.6 L/min showed more influence on the process performance of the relevant bioreactor. Lee et al. [21] tried to save aeration energy by modifying the activated sludge processes via employing two different methodologies namely adjusting on/off period of aeration at 60/45 min and changing the volume ratio of aerobic to anoxic tanks from 0.58 to 0.42. The acceptable results in terms of effluent COD, TN, NH_4^+, and TP concentration and also energy saving were obtained at reduced aeration time and volume. Fan et al. [15] assessed the performance of the activated sludge process at different levels of dissolved oxygen (DO) and achieved standard effluent criteria at low DO. In the research of Sánchez et al. [18], an activated sludge reactor with intermittent aeration regime was simulated and layout of aerators along with the influence of air flow rate per diffuser on the aeration efficiency was studied using computational fluid dynamics (CFD). From findings, energy consumption was improved by 2.8% and 14.5% via modifying air diffuser layout and reduction in air flow rate per diffuser, respectively. In other study, the activated sludge process was modified via adjusting aeration on/off period and altering volume ratio of aeration tank to anoxic tank to remove organic matters and nutrients [21]. Results showed that at decreased aeration time/volume, effluent COD, TN, NH_4^+, and TP concentrations were acceptable as well as significant energy consumption reduction. Banaei et al. [22] reported the arrangement of the aerators was a key factor affecting the performance of an industrial estate WWTP (Faraman's Industrial Estate, Kermanshah, Iran). In a study accomplished by Tocchi et al. [23], effect of several aeration regimes as on/off cycles of blower was investigated on performance efficiency of the activated sludge process treating dairy wastewater. The highest COD removal efficiency and ammonium degradation were obtained at on/off cycle of 30/45. Peng et al. [24] in their research evaluated the effect of extensive aeration on biological phosphorous removal (BPR) [24]. Obtained findings verified that extensive aeration had negative effect on the BPR. In other study, various aeration modes; point and step aeration; were analyzed on nitrogen removal efficiency [25]. Experimental results revealed that step aeration was more beneficial to both anoxic denitrification and simultaneous nitrification–denitrification (SND) compared to the point aeration. Impact of aeration patterns was checked on flow field in the wastewater aeration tank by Gresch et al. [26]. It was demonstrated which small changes in diffuser arrangement remarkably altered the overall flow field. Also, effect of various aeration levels and pure oxygen aeration on activated sludge properties and extracellular polymeric substances (EPS), respectively, was evaluated in details [27,28].

Based on the literature review, no work is reported considering investigation of the influence of installation angle of aerators on the performance of a full scale WWTP. Therefore, we were encouraged to study the impact of this variable (installation angles of aerators) in two levels of 30° and 45° on the process and operating performance of the aeration tank in a municipal WWTP working in Kermanshah, Iran. The aeration tank is divided into five consecutive channels by means of four baffles, thereby, a semi plug flow configuration is provided into the aeration tank. In each channel, eight propeller-aspirator-pumps are installed. The parameters investigated in this study were variations in DO, oxidation reduction potential (ORP), nitrogenous compounds, and phosphorous. Furthermore, kinetic coefficients were also determined.

2. Materials and method

2.1. Kermanshah's WWTP

The WWTP chosen for this research is located at southeast of Kermanshah province, Iran (with 857,048 populations). Fig. 1 shows the geographical position and overall view of Kermanshah's WWTP. The WWTP is being operated based on a CAS process comprised of four units; preliminary treatment (including screening, grit chamber), primary sedimentation, the secondary treatment (including aeration tank, secondary sedimentation), and chlorination units that receives flow rate of 60,000 m^3/d. The WWTP possesses four aeration tanks with dimensions of 40 m in length, 38 m in width, and 4m in height (working height of 3.2 m). Each

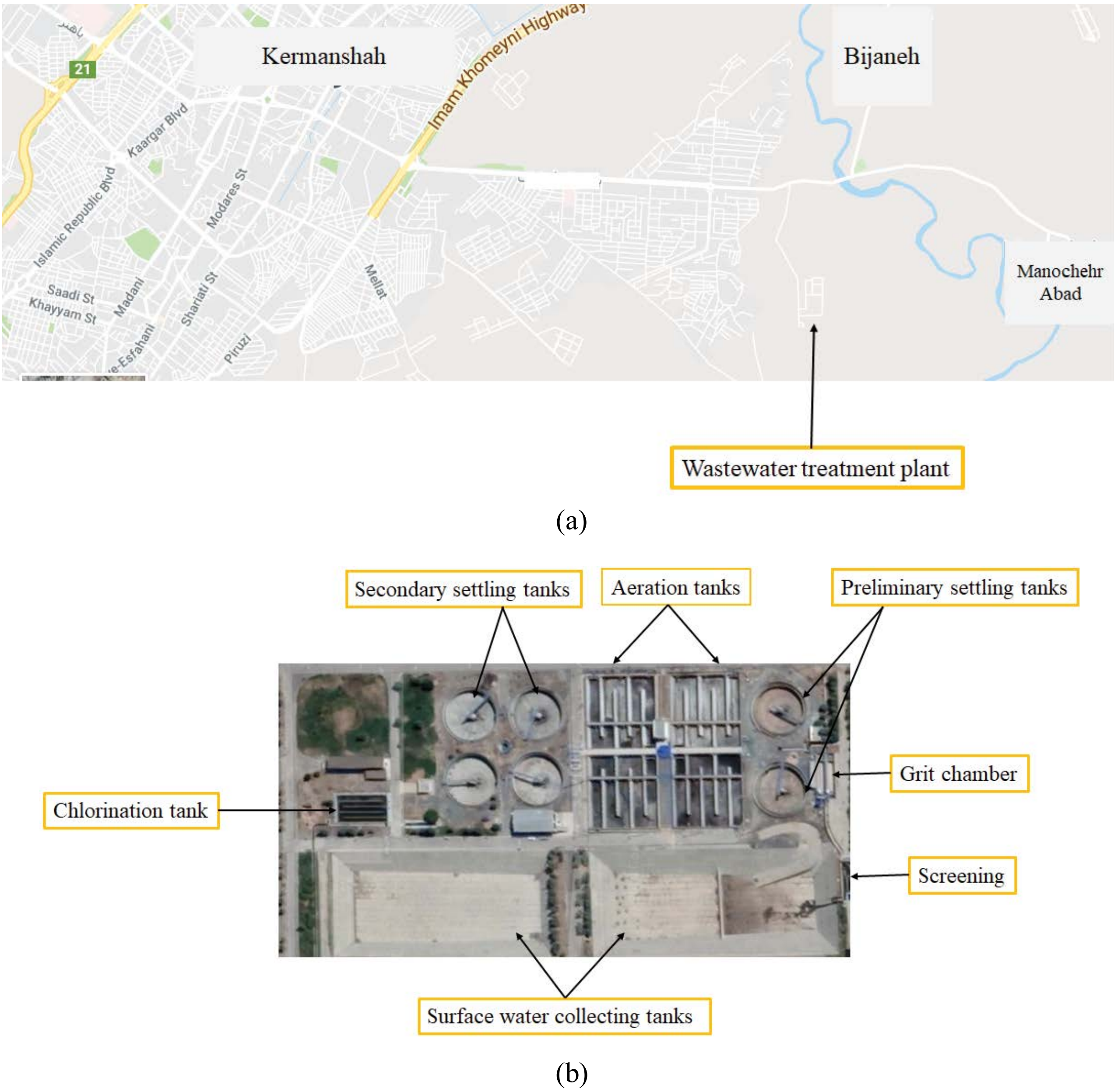


Fig. 1. (a) Geographical location and (b) process flow diagram of the Kermanshah's WWTP.

aeration tank was equipped to eight surface aerators in the shape of propeller-aspirator-pumps (Tornado model, 22 kW, 1,460 rpm, length of 368 cm, the width of 267 cm for each aerator) manufactured by Fluence Co., USA. Furthermore, each aeration tank was divided into five zones by means of four baffles that created semi-plug flow regime in the biological system. Fig. 2 displays a photo of the aerator used in the considered WWTP.

The values of some operating and process parameters such as hydraulic retention time (HRT), mixed liquor suspended solids (MLSS) and food to microorganism ratio (F/M) determined based on design criteria are 7 h, 2,000 mg/L, and 0.2 L/d, respectively. Influent wastewater characteristics of Kermanshah's WWTP are given in Table 1.

2.2. Description and operation of biological reactor

The influent and effluent quality characteristics of wastewater were analyzed as biological oxygen demand (BOD), COD, NO_3^-, NO_2^-, PO_4^{-3}, total Kjeldahl nitrogen, and (TKN) over a 4-month period from December 2017 to April 2018. Sampling was conducted from the outlet of screening, primary, and secondary settling tanks at least four times per month.

The aerators with two various installation angles, that is, 30° and 45° relative to the perpendicular were mounted into the aeration tanks. System stability was checked through the measure of ORP and dissolved oxygen (DO) after 1 week of operation at various installation angles. Fig. 3a exhibits sampling locations represented as small rectangles

Fig. 2. Photo of a propeller-aspirator-pump used in Kermanshah's WWTP.

Table 1
Influent wastewater characteristics of Kermanshah's WWTP

Parameters	Amount, mg/L		
	Maximum	Minimum	Average
COD	307	5.143	202.46 ± 81.75
BOD_5	235	70	153.75 ± 82.5
NO_2^-	324.0	00.0	0.18 ± 0.16
NO_3^-	22.4	19.2	2.88 ± 1.02
TKN	36.45	4.22	29.84 ± 11.48
TN	73.49	29.25	32.97 ± 12.22
PO_4^{3-}	3.27	3.1	1.85 ± 0.985

with a surface area of 2.5 cm^2 × 3 cm^2 to measure the ORP and DO. Overall, sampling was conducted in left-, middle-, and right-sides of each aeration tank addressed as *A*, *B*, and *C*, respectively. Therefore, 15 points at the length of and 13 points at the width of the aeration tank were considered to measure the ORP and DO. The ORP was assessed only at 0.5 m depth, while the DO was investigated at three depths, that is, 0.5, 1.5, and 2 m. In the next step, the angle of aerators was altered to 45° with respect to perpendicular, and then evaluation was done the same as the previous angle. In general, for each angle, 585 points for the measure of DO and 195 points for the measure of the ORP were considered according to calculations as follows:

DO sampling points = 13 × 15 × 3 = 585

ORP sampling points = 13 × 15 × 1 = 195

By changing installation angle of aerators, process parameters of BOD, COD, NO_3^-, NO_2^-, TKN, and PO_4^{3-} were measured at three different regions of each zone (i.e., beginning, middle, and end), created by baffles inside the aeration tank, as well as inlet and outlet streams. The parameters were measured three times. Accordingly, 17 regions were chosen for sampling (Fig. 3b). MLSS concentration was monitored as well. Based on Fig. 3b, sampling was conducted in left-, middle-, and right-sides of and various depths of each zone inside the aeration tank (0.5, 1.5, 2.5, and 3.2 m) for each given point. Accordingly, 12 samplings were carried out. Eventually, at an optimum angle, the MLSS concentration profile was prepared by sampling at 180 points.

In addition, the biological treatment system capacity was determined at four sludge retention times (SRTs; 13.89, 15.05, 22.54, and 31.84 d) in terms of quality parameters of COD, total suspended solids (TSS), NO_2^-, and NO_3^-. In this situation, the sludge recycling degree and MLSS concentration were also monitored. pH was monitored throughout the experiments. It remained in the range of 7–7.5 during this study. The temperature was reported to be averagely 14°C ± 4°C and 20°C ± 3°C in the winter and the summer, respectively. Obtained data were analyzed using SPSS software (Ver. 16.0).

2.3. Kinetic evaluation

The kinetic study was accomplished using Monod's model. In this work, the following expressions were used to calculate biokinetic coefficients (Y_{obs}, k_d, k, k_s, and μ_{max}):

$$\frac{1}{\mathrm{SRT}} = YU - k_d \tag{1}$$

$$\frac{1}{U} = \frac{1}{S} \times \frac{k_s}{k} + \frac{1}{k} \tag{2}$$

$$k = \frac{\mu_{max}}{Y} \tag{3}$$

where, SRT, *Y*, and *U* are SRT (d), yield (g VSS/g COD_{rem}), and specific microbial growth rate (mg COD/mg VSS d), respectively. k_d refers to endogenous decay rate (1/d); and *S* stands for effluent COD (mg/L). *k* is maximum substrate consumption rate (mg COD/mg VSS d). k_s and μ_{max} are

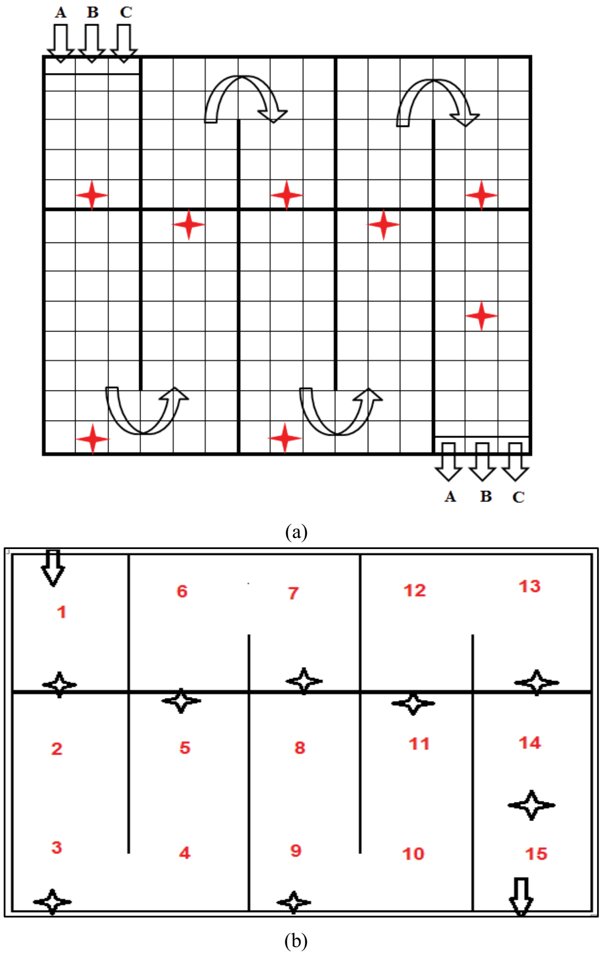


Fig. 3. Sampling regions for the measure of (a) DO and ORP, a sign of shows the aerator and (b) COD, BOD, MLSS, TN, and TP. *Note*: all aerators but last one were installed at the opposite direction of the flow.

defined as half-velocity constant (g COD/L) and maximum specific microbial growth rate (1/d), respectively.

2.4. Analytical procedures

Following parameters were analyzed according to Standard Methods: BOD, COD, MLSS, mixed liquor volatile suspended solids (MLVSS), NO_2^-, NO_3^-, TKN, and PO_4^{-3} [29]. The ORP and DO were measured using a portable pH meter equipped by ORP sensor (WTW/pH.3110.2AA112) and DO meter (WTW/Oxi.3205/2BA103), respectively.

3. Results and discussion

3.1. Variations of MLSS concentration inside the aeration tank at two different angles of aerators installation (30° and 45°)

Fig. 4 shows average MLSS concentration at the length of the aeration tank once the aerators were mounted at two different angles, 30° and 45°. As seen in Fig. 4, the average MLSS concentration at 10 point is very high for both angles, which verifies inadequate mixing, and consequently sludge accumulation in this region. When the aerators were mounted at 30° angle, the MLSS concentration is approximately the same throughout the aeration tank and its fluctuation is relatively slight except the 10 point. Overall, the MLSS concentration at 30° angle of aerators is higher (around 1,000 ± 52.96 mg/L) compared to that of 45° angle of aerators attributed to the sludge accumulation due to inadequate mixing.

3.2. Variations of DO concentration

Changes of the DO concentration at the length of aeration tank at 30° and 45° angles of aerators and different depths of 0.5, 1.5, and 2 m are displayed in Figs. 5 and 6. The sampling was done at different regions of the aeration tank namely right-, middle-, and left- sides of the aeration tank.

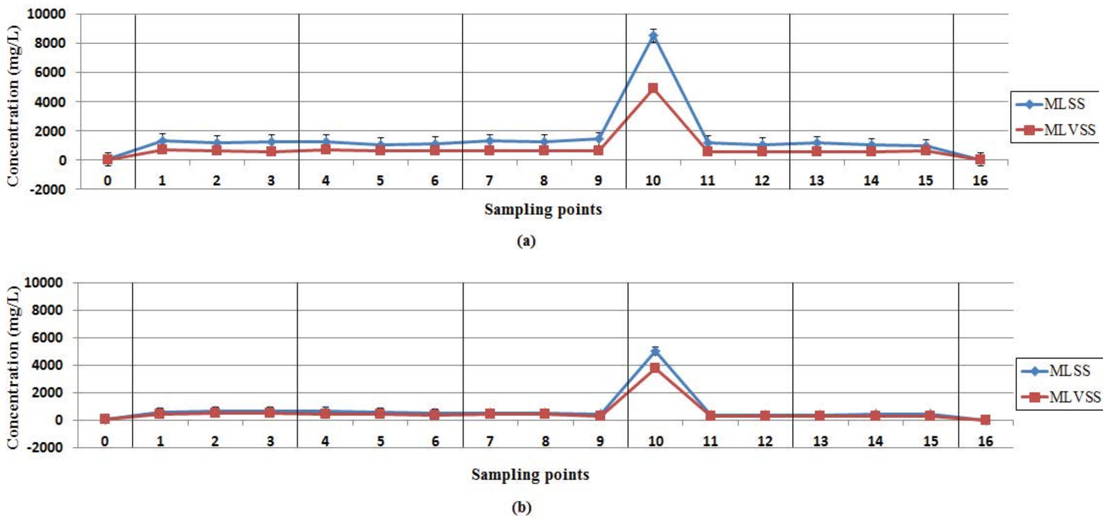


Fig. 4. Variations of the MLSS concentration at the length of the aeration tank at two different angles of aerators installation (a) 30° and (b) 45°.

From Figs. 5 and 6, it is explicit the aerators have indicated a direct effect on the DO concentration. Furthermore, the installation location of the aerators and also their number were identified as effective factors in the variations of the DO concentration. At 30° angle, prior to each aerator, the increase in the DO concentration is obviously attributed to the opposite installation of aerators with respect to flow direction. In contrast, reduction in the DO concentration was observed after the aerators, related to the DO consumption during biological activities. Maximum and minimum DO concentrations are 3.2 ± 0.25 and 0 mg/L, respectively. It is important to be noted there were only few points, at the 2 m depth of the aeration tank, with the DO concentration of 0 mg/L. The average DO concentration at this angle was around 1 mg/L. Based on findings obtained in this study, effect of the aerators on the DO concentration was different at length, width, and height of the aeration tank. Generally, at the length of the aeration tank with common piston flow constituted from several channels, the DO concentration firstly reduces because of its high consumption rate, then uniformly increases. By contrast, in this treatment plant, the DO concentration alternatively increased and decreased as a result of low influent feed as well as low food to microorganism ratio (F/M).

The changes of the DO concentration at the 45° angle of the aerators and at different depths of 0.5, 1.5, and 2 m are presented in Figs. 5b, d, and f. As shown in Fig. 5, the changes trend of the DO concentration at this angle is different from the 30° angle. So that at first 90 m from the inlet of aeration tank even with the existence of four aerators, the DO concentration was very low, even less than 0.5 ± 0.3 mg/L. From the middle of the third part of the aeration tank, the DO concentration increased and reached average amounts of 2 ± 0.9–2.5 ± 0.5 mg/L. Based on the results, in some parts of the aeration tank, in which the DO concentration is extremely low, a large amount of the sludge has accumulated due to a lack of enough energy. The maximum and minimum values of the DO concentration obtained in this study were 3.6 ± 0.6 and 0 mg/L, respectively.

The results of the present study were in the agreement with the research group of Kumar et al. [16]. The authors have reported which the highest DO concentration was obtained at 75°.

3.3. Variations of ORP

In this study, the ORP was measured only at the 0.5 m depth of the aeration tank. It has been claimed operating conditions can be predicted using the ORP data, for example, how much loading or the DO has been applied to the aeration tank [30]. Figs. 6a and b show the variations of the ORP at different regions of the aeration tank at 30° and 45° angles, respectively. It can be observed from Fig. 6a, at the first three regions of the aeration tank, the ORP has shown an incrementally trend and its values increased from 0 to 150 mV. Whereas, at last two regions of the aeration tank, the changes in the ORP were low (from 150 to 200 mV).

Generally, the ORP changes at a 45° angle revealed an increasing trend. The results are displayed in Fig. 6b. At the beginning parts of the aeration tank where the DO concentration was less than 0.5 ± 0.02 mg/L, the ORP values changed from –50 to +50 mV. Similar consequences were reported in other studies [31,32]. Finally, the ORP values were incremented to 150 mV. In overall, changes in the ORP correspond with the changes in the DO concentration, so that the more DO concentration, the more the ORP values. These two parameters (DO and ORP) can monitor different process conditions, that is, anaerobic, anoxic, and aerobic conditions. By decreasing them the process conditions would change from the aerobic condition to the anoxic and then the anaerobic conditions depend on changes degree (aerobic conditions: ORP <+100, DO = 3–4 mg/L; anoxic conditions: ORP = –100 to +100, DO = 0.1 mg/L; anaerobic conditions: ORP < –100, DO: 0 mg/L).

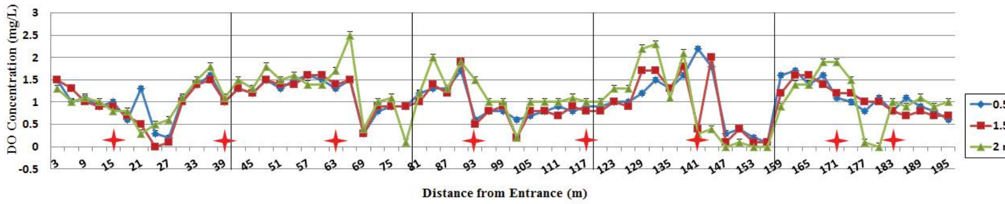
The average amounts of the DO concentration compared with the ORP at the 0.5 m depth and the angles of 30° and 45° are depicted in Figs. 7a and b. As mentioned above, the more DO, the more the ORP biological system would have. On the other hand, mixing of liquor bulk gives rise to a decrease in the ORP. Since the mixing accelerates oxidation reactions, oxygen consumption, and consequently organics and nutrients removal [33–35]. At the 30° angle, the ORP increased at the length of the aeration tank due to the increase in the DO as well as the decrease in the COD content. This conclusion was in accordance to a study of Tanwar et al. [35]. While at the 45°, the opposite trend was observed and the amount of the ORP reduced as low DO level, which implies the appearance of anoxic conditions and sulfate reduction [31]. At the 30° angle, minimum DO concentration (less than 0.5 ± 0.03 mg/L) was related to the beginning part of the aeration tank, between aerators and at the end of the fourth part of the aeration tank, in which the ORP had the lowest value (less than zero). Whereas, the maximum concentration of the DO and ORP (2.5 ± 0.5 mg/L and 200 mV, respectively) was recorded in the fourth part of the aeration tank and around the aerators. At the 45° angle, the minimum concentration of the DO and ORP was about 0.1 ± 0.01 mg/L and –50 mv, respectively, obtained at the beginning part of the aeration tank and after the first aerator. The maximum values of the DO and ORP were 3.3 ± 0.1 mg/L and 120 mv, respectively, achieved at the beginning of the fourth part of the aeration tank.

3.4. Variations of COD

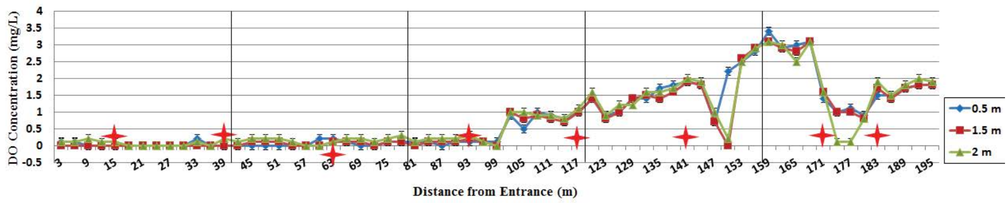
Fig. 8a exhibits the average changes of COD concentration at the length of the aeration tank and the 30° angle of the aerator installation. Based on the Fig.8, soluble COD concentration reduced from 105 ± 1.13 mg/L in inlet flow to 40 ± 0.39 mg/L in the outlet flow.

However, at the 45° angle, the COD concentration decreased from 115 ± 0.25 mg/L in the inlet flow to 21 ± 0.27 mg/L in the outlet flow. Reduction in the COD concentration continued from the inlet of aeration tank till sampling 9 point. While, the reverse trend was detected at 10 point and the COD concentration was incremented. It might be due to the degradation of cell debrides which have accumulated inside the aeration tank. After sampling 12 point, significant changes at the COD concentration did not occur.

The COD concentration showed some fluctuations at the length of the aeration tank, although flow rate was constant. This observation was ascribed to semi plug flow



(a)



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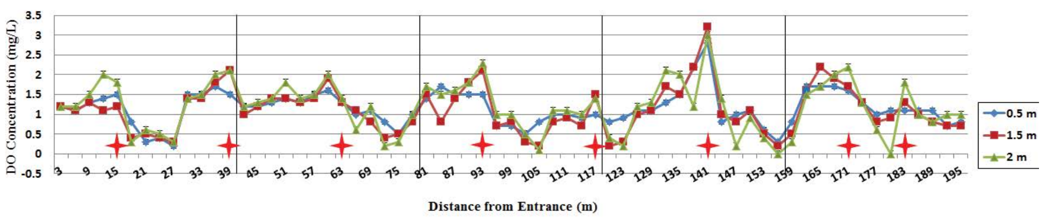

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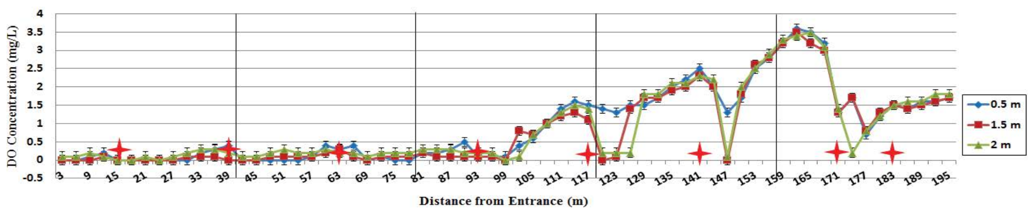

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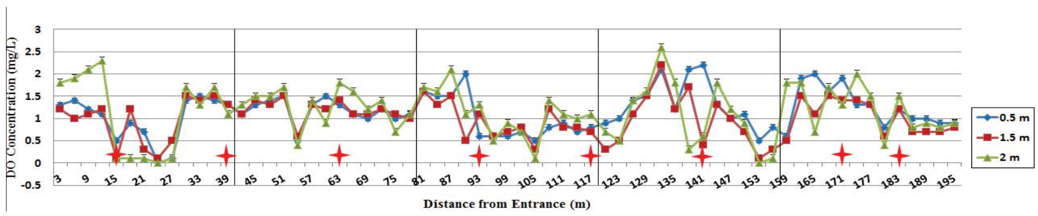

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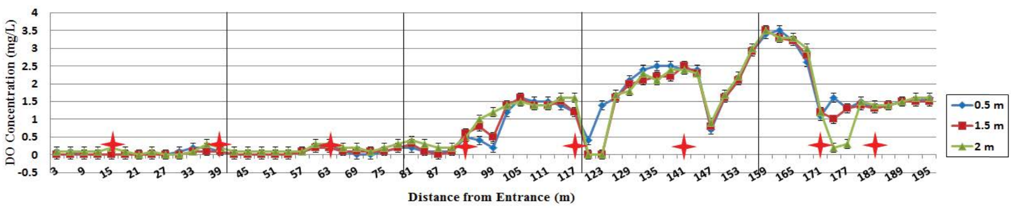

(f)

Fig. 5. Variations of the DO concentration at the length of the aeration tank at different angles of the aerators installation and different regions of the aeration tank, (a) 30° and right side; (b) 45° and right side; (c) 30º and middle side; (d) 45° and middle side; (e) 30° and left side; and (f) 45° and left side.

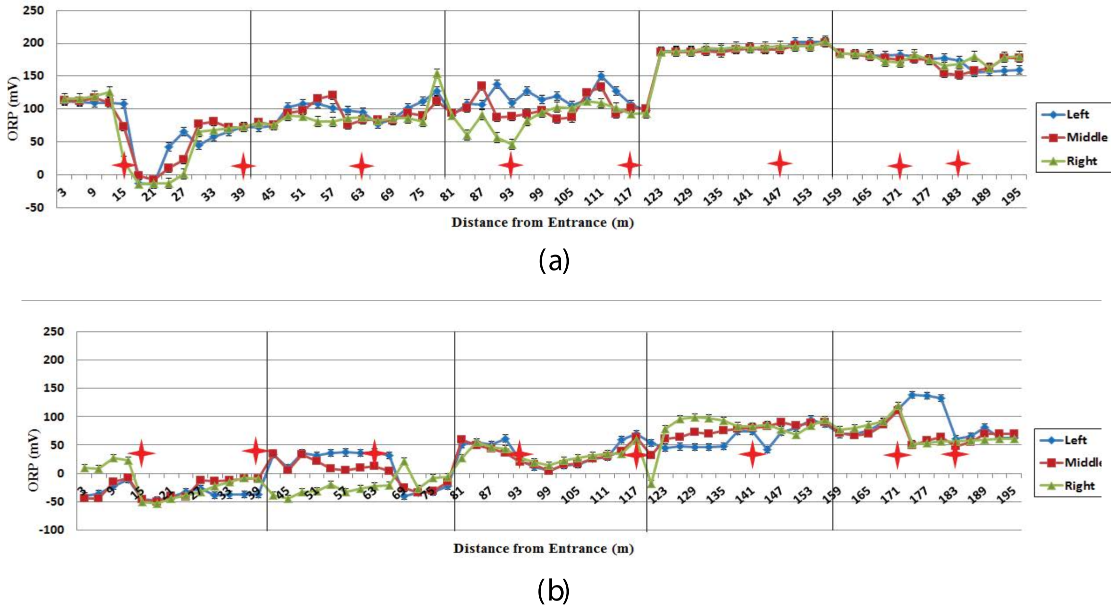

Fig. 6. Variations of ORP at the length of the aeration tank at the 0.5 m depth and the angles of (a) 30° and (b) 45°.

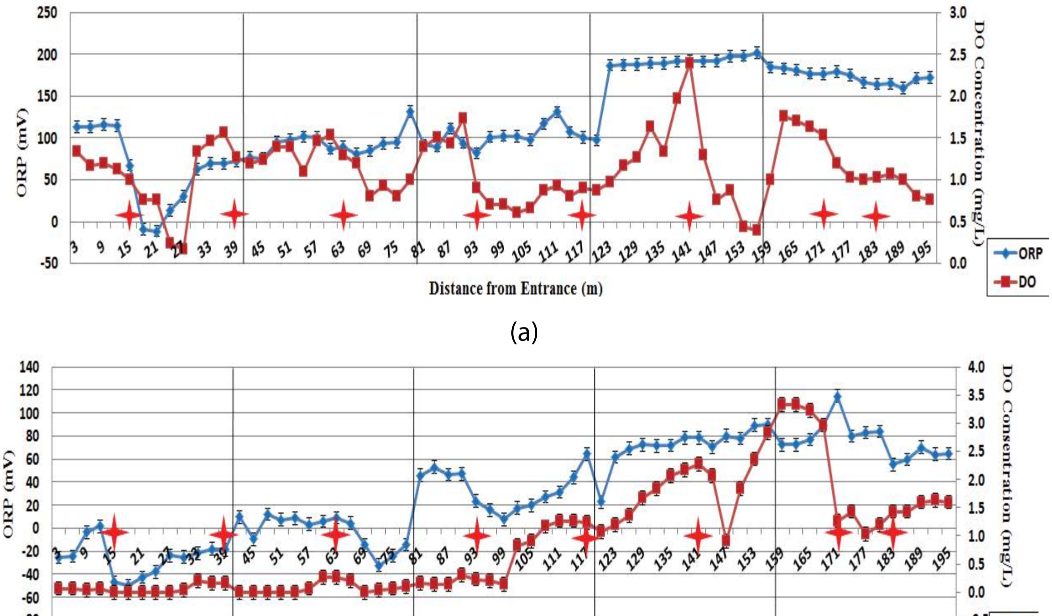

Fig. 7. Average variations of the DO and ORP at the length of the aeration tank and the 0.5 m depth, (a) at the 30° and (b) 45° angle.

regime. Also, conversion of suspended COD and refractory compounds into soluble COD by microorganisms can be considered as another reason for such fluctuations. Moreover, organic loading rate (OLR) values applied to this treatment plant were less than the design criterion, which could be considered as the main factor at changes of the COD concentration. Several studies have confirmed high COD removal would obtain at high DO concentration [25,27,36]. However, this plant was operated with low influent COD (even less than the design criterion), that's why effluent COD met the permissible standard.

3.5. Variations of nitrogenous compounds

Findings obtained from this study indicated change at the angle of the aerators installation had an obvious impact

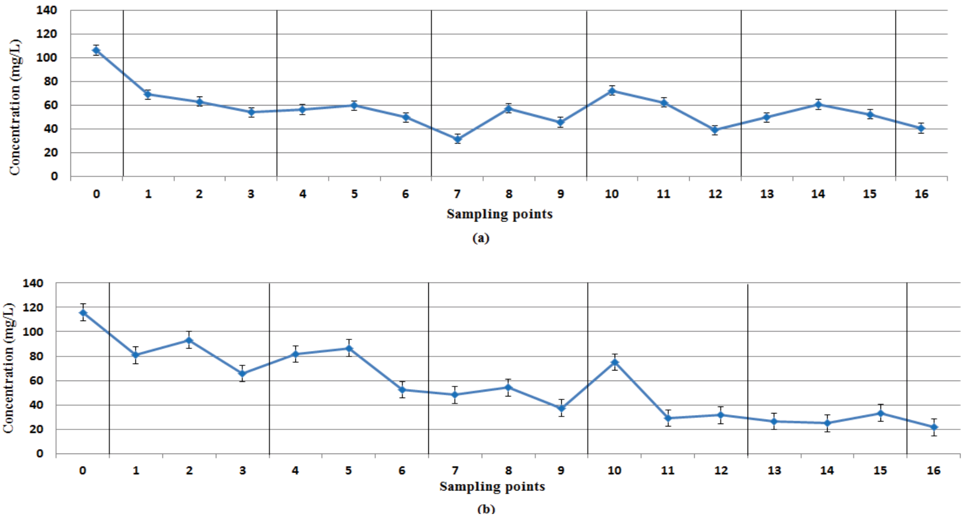

Fig. 8. Average variations of the COD concentration at the length of the aeration tank at angles of (a) 30° and (b) 45°.

on the DO concentration inside the aeration tank. So, considering these two different angles, the aeration tank would experience two different circumstances. The changes in the nitrogenous compounds as TKN, NO_3^-, NO_2^-, and TN at the length of the aeration tank and the angles of 30° and 45° were shown in Figs. 9a and b, respectively. As displayed in Fig. 9a, NO_3^- concentration had an increasing trend from 2 ± 0.26 to 14 ± 0.16 mg/L, where verifies the nitrification process. While TKN showed a decreasing trend from 24 ± 0.1 to 7 ± 0.1 mg/L at sampling 6 point. NO_2^- concentration was almost zero, attributed to the presence of enough DO concentration inside the aeration tank, whereby, nitrite ions produced from influent NH_4^+ were converted into nitrate ions quickly.

Fig. 9b exhibits the changes of the nitrogenous compounds at the length of the aeration tank at 45° angle of the aerators installation. Based on the results, aeration at this angle has provided a condition for an anoxic process.

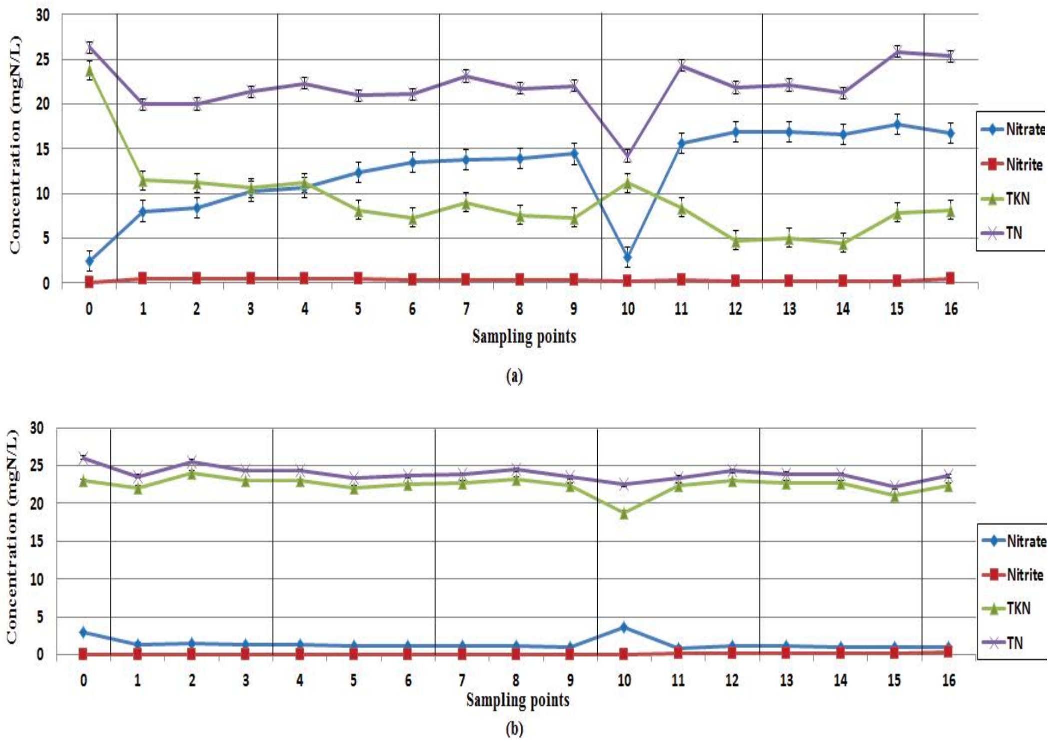

Fig. 9. Average variations of the nitrogenous compounds at the length of the aeration tank and different angles of (a) 30° and (b) 45°.

However, results confirmed the 45° angle had no considerable influence nitrogen removal.

From Fig. 9, a break has been appeared at the 10 point due to the sludge accumulation and its subsequent degradation that led to releasing organics and ammonia nitrogen. As discussed above, the changes trend observed in the nitrogenous compounds were opposite at examined angles. Such behaviors were correlated to inlet stream characterization. So that at the 30° angle, influent wastewater was enriched by NO_3^-, while the TKN concentration was kept at a low level. Whereas, at the 45° angle, the inlet wastewater flow showed the opposite characteristics contained low NO_3^- and high TKN. Therefore, it can be inferred that different biological processes have taken place at the different installation angles due to various inlet wastewater characteristics and the changes in DO concentration. At the 30° angle, heterotrophic strains have more compatibility due to high NO_3^- content, so the denitrification process was dominated, whereas, at the 45° angle, autotrophs grow due to high TKN contents, and thus nitrification process prevailed [37–40]. In spite of presence of such diverse species responsible for nitrification and denitrification processes, a noticeable reduction in TN contents was not detectable. Since high sludge accumulation in some parts of the aeration tank and its degradation are a potential source of nitrogenous compounds, furthermore, the ORP changes at the length of the aeration tank influence mass balance of the nitrogenous compounds.

3.6. Variations of phosphorous concentration

The variations reported at phosphorous concentration at the length of the aeration tank for both angles were little. Changes profile of the phosphorus concentration is displayed in Fig. 10. As presented in Fig. 10a, no remarkable change was observed at the phosphorous concentration at the 30° angle due to completely aerobic condition. While, slightly decreasing trend was detected at the 45° angle. Since at entrance of the aeration tank, anaerobic condition was dominated, then at the length of the aeration tank, the DO concentration was slowly increased, thereby, anoxic, and oxic conditions were provided. Although desired conditions for phosphorus removal have been created inside the aeration tank, changes in the phosphorus concentration were not appreciable owing to the low concentration of influent phosphorus, less than 5 ± 0.1 mg/L. At the sampling 10 point for both angles, the phosphorus concentration increased from which degradation of the accumulated cells had given rise to releasing phosphorous compounds.

3.7. Variations of MLSS concentration at optimized angle (30°)

The variations of the MLSS concentration at three different regions of the aeration tank; left-, middle-, and right-side; are depicted in Fig. 11. This profile was related to four depths viz. 0.5, 1.5, 2.5, and 3.2 m. However, only

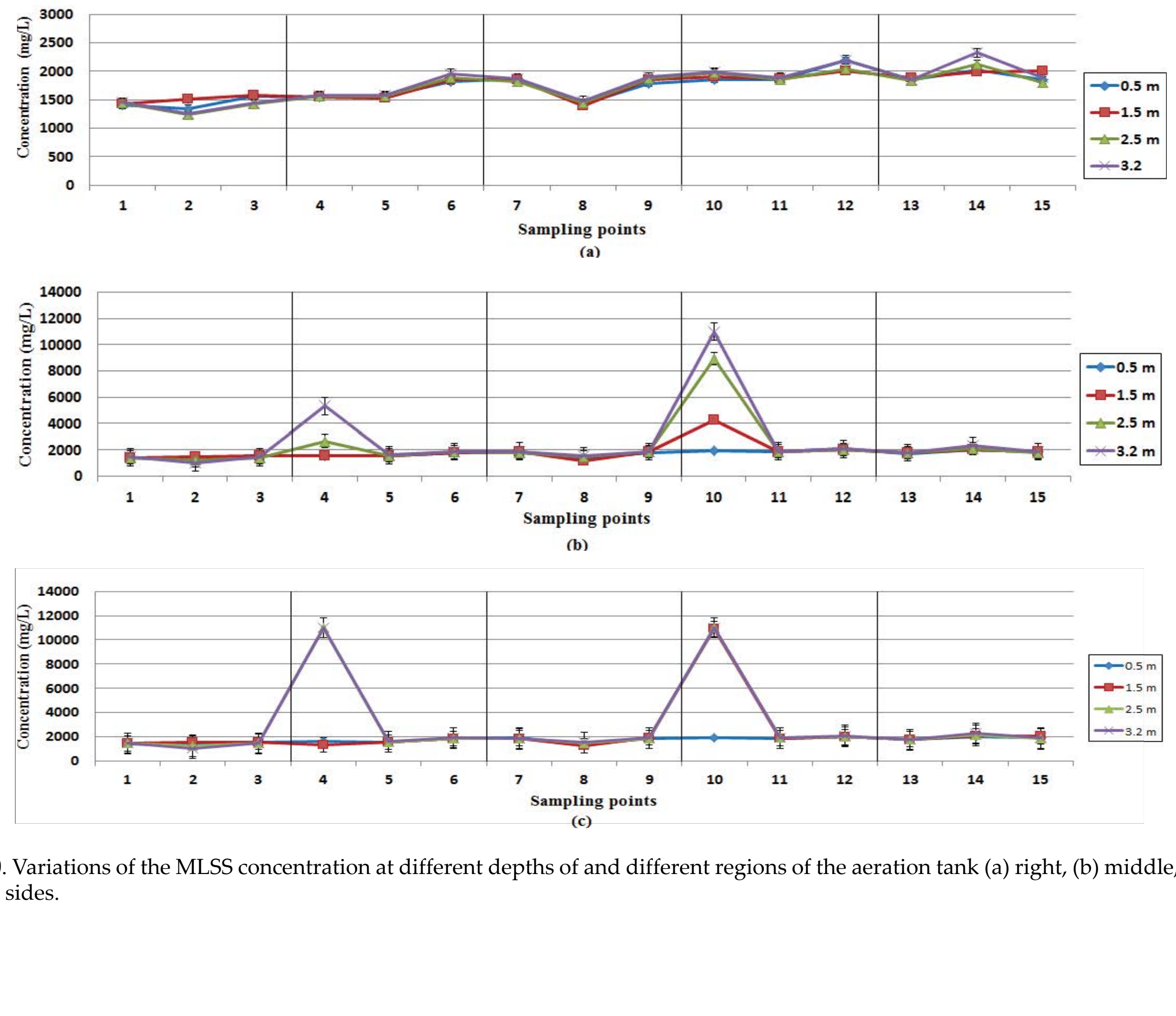

Fig. 10. Variations of the MLSS concentration at different depths of and different regions of the aeration tank (a) right, (b) middle, and (c) left sides.

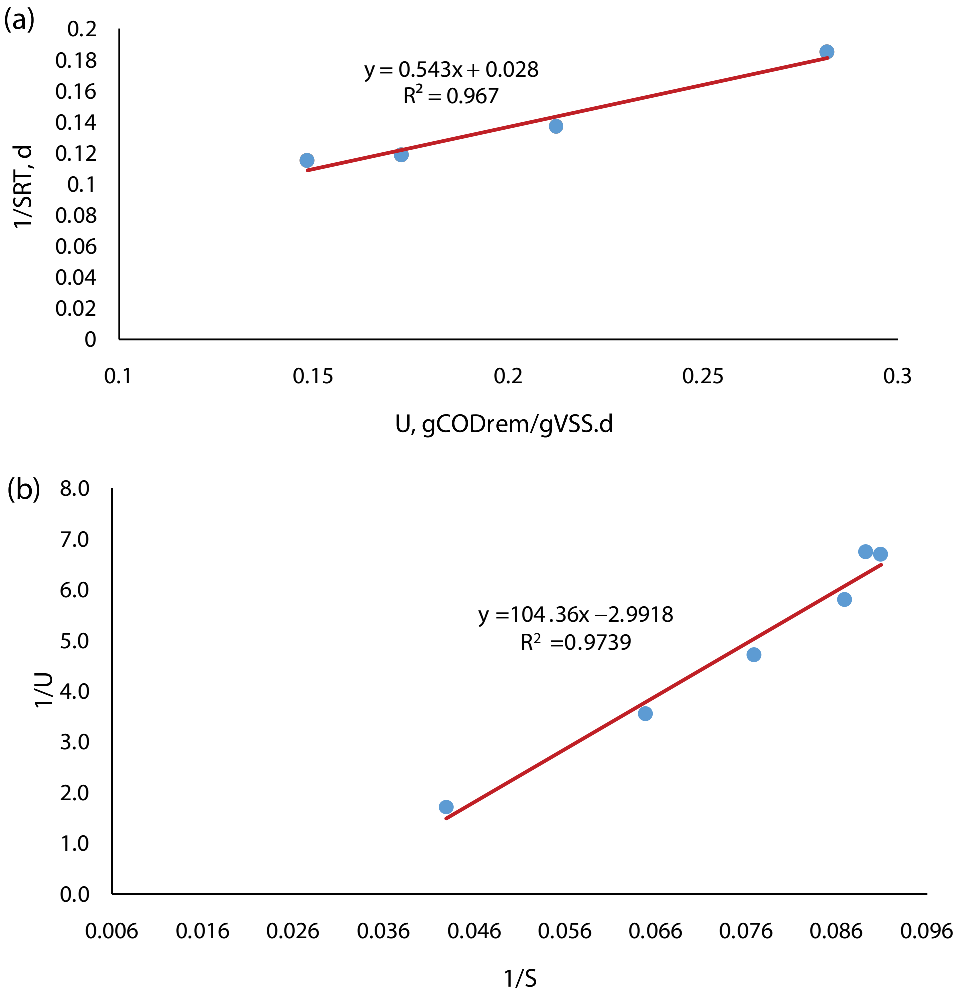

Fig. 11. Determination of the kinetic coefficients based on (a) specific microbial growth rate (U) vs. 1/SRT and (b) reverse COD removal (1/S) vs. reverse specific microbial growth rate (1/U).

the depth of 3.2 m was identified as a suitable depth for sampling without any sludge sedimentation. Fig. 11a shows the variations of the MLSS concentration at the right side of the aeration tank. From Fig. 11, there was an increase in the MLSS at points of 6, 12, and 14. The points of 6 and 12 were located at the edge of the aeration tank, while the 14 point was placed behind the last aerator, therefore, there was not the adequate mixing at these three points which resulted in the MLSS accumulation and finally an increase at the MLSS concentration. At the middle and left sides of the aeration tank, increment in the MLSS concentration was observed at the 4 and 10 points due to lack of appropriate mixing and sludge accumulation.

3.8. Effect of SRT on the performance of the biological treatment system

In an overall investigation, the influent and effluent COD concentrations of the aeration tank at different SRTs (13.89, 15.05, 22.54, and 31.84 d) were discussed. In this study, although incoming COD concentrations to the aeration tank were low (80 ± 5.2–137 ± 0.04 mg/L), there were still some remained COD concentrations in the effluent flow, in the range of 23 ± 0.07 to 43 ± 0.15 mg/L. It can be noted that the low efficiency of the biological system, ranging from 58.75% ± 0.3% to 75.91% ± 0.1%, doesn't mean its low capacity. These results were ascribed to the cell lysis phenomenon which happens at famine conditions in which the biological system has not received enough food (COD) in comparison with biocatalyst (MLSS, 1,382 ± 2.08–2,178 ± 2.22 mg/L) concentration existed in the aeration tank. Generally, by providing high loading of the influent COD, high treatment capacity, and subsequently high COD removal is more plausible. As a conclusion, the most COD removal efficiency was related to the SRT of 22.5 d due to high influent COD concentration.

3.9. Kinetic evaluation

In this study, the kinetic parameters were estimated using Monod's model and results are presented in Table 2. To determine kinetic coefficients, plots of the variations of 1/SRT vs. U, and also the variations of 1/U against 1/S are depicted in Figs. 11a and b, respectively. The kinetic

Table 2
Parameters obtained from the aeration tank of Kermanshah's WWTP

VSS, mg/L	COD_{in}, mg/L	COD_{out}, mg/L	COD_{rem}, mg/L	HRT, d	TSS_{eff} mg/L	SRT, d	1/SRT 1/d	1/*S*, L/mg	*U*, mg COD/mg VSS d	1/*U*, 1/(mg COD/mg VSS d)	*F*/*M*, g COD/g VSS d	OLR, g COD/m^3 d
453	112	41	63.4	0.33	50	2.94	0.340	0.087	0.475	2.105	0.75	0.34
301	120	67	44.2	0.33	40	2.44	0.410	0.076	0.534	1.874	1.21	0.36
491	98	41	58.2	0.33	54	2.95	0.339	0.089	0.352	2.843	0.60	0.29
900	88	6.5	92.6	0.33	90	3.24	0.308	0.090	0.274	3.644	0.30	0.26
334	133	61	54.1	0.33	60	1.81	0.554	0.064	0.653	1.531	1.21	0.40
866	233	41	82.4	0.33	14	20.06	0.050	0.043	0.672	1.488	0.82	0.70
830	80	33	58.8	0.33	20	13.46	0.074	0.087	0.172	5.828	0.29	0.24

coefficients nominated as k_d, Y, k, and k_s were determined from the intercept and slope of Fig. 11. The obtained results are represented in Table 2. Y_{obs} of 0.54 g VSS/g COD_{rem} and k_d of 0.028 1/d were obtained. As a final conclusion, obtained bio-kinetic coefficients in this study were in the agreement with other WWTPs well being operated in Sarpol-e-Zahab and Paveh cities (Kermanshah, Iran) which confirms the proper performance of the biological treatment process (Table 3).

The variations of MLVSS to MLSS ratios are indicated in Fig. 12. As it can be seen from Fig. 12, the MLVSS content was in the range of 300–900 mg/L. From Fig. 12, it is obvious that the MLVSS to MLSS ratio highly varied at the length of the aeration tank, and the average amount reported was 0.68. At longer HRTs, uneven and uniform distribution of the biomass concentration inside the aeration tank as well as low influent COD concentration can be considered as reasons for changes observed in the MLVSS to MLSS ratios.

To better investigate kinetic parameters, the COD removal at different operating conditions was calculated (Table 4). COD amount consumed in this study was between 142 and 582 g/m^3 d. The results revealed once the MLSS was 850 mg/L by changing influent COD from 80 to 230 mg/L, effluent COD amount showed no remarkable change, and was around 30 mg/L throughout the experiments. COD consumption degree was 142 and 582 g/m^3 d at the influent COD of 80 and 230 mg/L, respectively. In addition, the sludge production rate was obtained to be between 43 and 175 g VSS/g COD_{rem} d at mass loading of 0–24.7 g/m^3 d.

Table 3
Comparison of bio-kinetic coefficients obtained from other WWTPs of Kermanshah province

Type of wastewater (WW)	*Y*, g VSS/g COD_{rem}	k_d, 1/d	μ_{max}, 1/d	k_s, mg/L
Sarpol-e-Zahab's municipal WW	0.47	0.0616	0.0085	3.7
Paveh's municipal WW	0.53	0.0182	0.033	15.3
Kermanshah's municipal WW (this study)	0.545	0.0281	0.015	34.9

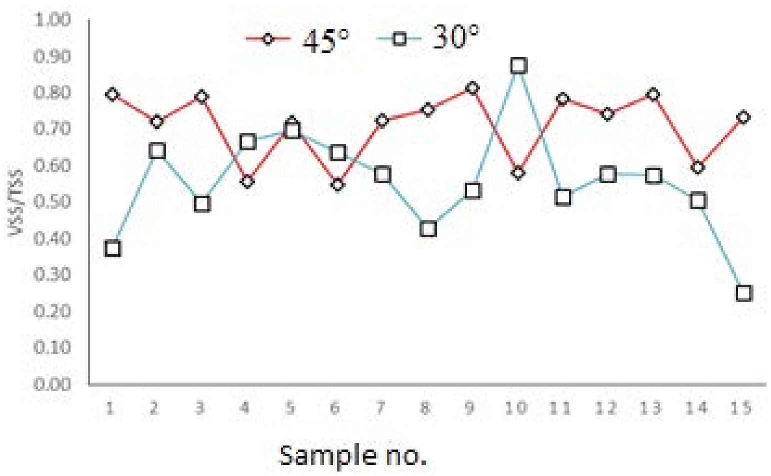

Fig. 12. Variations of the VSS to TSS ratio at the length of the aeration tank at different angles of the aerators installation.

Table 4
Kinetic parameters obtained in this study

k_s, mg/L	k, 1/d	Y, g VSS/g COD_{rem}	k_d, 1/d	μ_{max}, 1/d
34.9	0.334	0.544	0.0281	0.015

4. Conclusions

Aim of the present study was to investigate the effect of two aerators installation angles, that is, 30° and 45° on the biological treatment capacity of Kermanshah's WWTP. Generally, the aerators installation angles influenced on the DO and ORP values, substantially various biological processes. According to the results, the DO and ORP amounts at the 30° angle were more than those of the 45° angle. These angles had no significant effect on the remediation of organic matters attributed to low influent organic loading. The nitrogenous compounds removal was not influenced at the 45° angle due to slight changes in the DO level. Furthermore, the phosphorus removal was effectively not influenced by both studied angles, so that only little removal was observed at 45° angle for which anoxic and aerobic conditions were somewhat provided. As a final conclusion, results obtained from kinetic studies were in good agreement with literature.

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