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Effect of hydraulic retention time on intermittent cycle extended aeration system performance

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ملخص البحث

نظام التهوية الممتدة ذو الدورة المتقطعة (ICEAS) هو تعديل لنظام النبض المتتالي التقليدي حيث يتم ادخال التغذية المستمرة مع ابقاء التفريغ المتقطع للمياه المعالجة. تم وضع النموذج الحقلي بمحطة أبو رواش بالجيزه واستخدم لمعالجة مياه الصرف الصحي المعالجة اوليا. أن الهدف الرئيسي من هذا البحث هو دراسة تأثير مدة المكث الهيدروليكية علي أداء نموذج (ICEAS) الحقلي في معالجة مياه الصرف الصحي. تم دراسة ثلاث تجارب لمدد مكث هيدروليكية مختلفة (15 و 20 و 25 ساعات). مدة المكث الهيدروليكية المثلي لنظام التهوية الممتدة ذو الدورة المتقطعة هي 20 ساعه وكانت تركيزات المياه المعالجة عندها 10.50±1.83، 4.5±0.8، 5.6±2.1، 7.9±1.52، 0.55±0.09، 0.9±0.6 ملجم / لتر للاكسجين الكميائي المستهلك، والاكسجين الحيوي المستهلك، المواد الصلبة الكلية، النيتروجين، الأمونيا، الفسفور علي الترتيب التي تتوافق مع التنظيمات المحلية والدولية. إن زيادة مدة المكث عن 15 ساعة لم تحسن من أداء نظام التهوية الممتدة ذو الدورة المتقطعة في ازالة الفسفور. يعتبر نظام التهوية الممتدة ذو الدورة المتقطعة تكنولوجيا فعالة في معالجة مياه الصرف الادمية من حيث ازالة المواد العضوية وتحقيق النترجة وازالة النيتروجين والفسفور

ABSTRACT

Intermittent cycle extended aeration system (ICEAS) is a modification of conventional sequencing batch reactor in which continuous feed flow and batch outlet flow are considered. The ICEAS pilot scale was located at Abu-Rawash wastewater treatment plant, Giza, Egypt. The pilot was used to treat the preliminary treated domestic wastewater. The main objective of this research is studying the effect of hydraulic retention time on the ICEAS pilot scale performance for domestic wastewater treatment. Three different total hydraulic retention times (HRTs) of 15, 20 and 25 hours were studied. The optimum HRT for wastewater treatment by intermittent cycle extended aeration system is 20 hours. Under the optimum HRT of 20 hours, effluent concentrations in terms of COD, BOD_5 and TSS, TN, NH_4-N and TP were 10.50±1.83, 4.5±0.8, 5.6±2.1, 7.90±1.52, 0.55±0.09 and 0.9±0.6 mg/l which is complying with the local and international regulations. Increasing HRT more than 15 hours did not significantly improve the ICEAS performance in terms of TP effluent concentration. The intermittent cycle extended aeration system is an effective technology in wastewater treatment in terms of orgaic removal, nitification, TN and phosphrus removal.

Keywords: Sequencing batch reactor, Intermittent cycle extended aeration system, Hydraulic retention time, Organic removal, Nitrogen removal, Phosphorus removal

1. Introduction

Wastewater contains carbon, nitrogen, phosphorus and sulfur (Sedlak, 1991). Presence of nitrogen and phosphorus in water bodies generally results in eutrophication of these water bodies (Carpenter et al., 1998; Luostarinen et al., 2006). Many types of biological nitrogen and phosphorus removal systems are able to remove nitrogen and phosphorus

to the level of eutrophication control (U.S EPA, 2010). These systems consist of anaerobic, anoxic and oxic zones for removing phosphorus and nitrogen and require greater hydraulic retention time (HRT), consequently larger foot-print (Metcalf and Eddy, 2014). Among these systems, sequencing batch reactor (SBR) which is a single complete-mix tank of activated sludge operated in periodical series phases (U.S. EPA, 2010). SBR main advantages are; less required foot-print and elimination of final clarifier (U.S. EPA, 1999). In spite of the attractive advantages of conventional SBR, it suffers from many practical shortcomings (Mahvi et al., 2004; Khursheed et al., 2012).

Intermittent Cycle Extended Aeration System (ICEAS) is a modification of SBR system, which was developed to overcome the conventional SBR problems (Chen et al., 2001). ICEAS is adjusted to be operated in a continuous flow, while maintaining other SBR cycle steps. ICEAS cycle steps consist of react, settling, decanting and wasting phases. ICEAS consists of two chambers separated by baffle wall (pre-react and main react zones). ICEAS receives wastewater during all phases of its cycle into pre-zone, so it is not interrupted during the settling and decanting phases (U.S EPA, 1992; Mahvi et al., 2004).

ICEAS needs a large HRT (20 and 40 hr) same as SBR (Metcalf and Eddy, 2014). The effects of operating conditions on the ICEAS performance have been reported in the literature. Mahvi et al, (2004) reported that the BOD_5 removal by ICEAS for domestic wastewater treatment was more than 96.8% at HRT range of 12-16 hr. However, TN removal was 85, 70 and 58% at HRTs of 16.7, 14 and 12.4 hrs respectively. Aghapour et al, (2013) reported that the COD removal is significantly decreased when HRT reduced to 13 hr. Ouyang & Juan (1995) reported that the TN removal was 65% and 71 at HRTs of 12 and 18.4 respectively. However, TP removal was 68 % at HRT of 12 and 18.4 hrs. Ghehi et al., (2014) applied intermittent aeration in ICEAS and achieved TN and TP removals of 88.3% and 81.9% respectively at HRT of 20.8 hrs.

Most literature, there are not so much study on the effect of HRT on the intermittent aeration pattern. From the literature, most of the reported studies were focus on the ICEAS technology with continuous aeration. However, only limited studies are reported on studying the ICEAS system operated under intermittent aeration pattern. So, the purpose of this research is to study the effect of HRT on the performance of ICEAS pilot scale in terms of organic matter, nitrogen and phosphorus removal in wastewater treatment under intermittent aeration pattern

2. Materials and methods

2-1 ICEAS experimental set-up and operation

Figure 1 shows the carbon steel pilot scale of the ICEAS system that was used in this study. The pilot sizing was 40 cm width, 120 cm length and 60 cm water depth with working volume of 288 liters. The reactor consists of pre-zone with 10% of total volume and main-zone. The pre-zone continuously receives raw wastewater by a submersible pump. Then, the wastewater passes through openings at the baffle wall to the main zone. During the react period, air compressor is used for intermittent air supply. The air flow through perforated thin hoses at the bottom of the main zone. Mechanical mixer is used to agitate the mixed liquor in the main zone. However, the recirculation pump is used to prevent the settling of biomass in the pre-zone. At the end of the reaction phase and before the beginning of settling phase of each cycle, a portion of mixed liquor was removed by excess sludge pump to maintain the desired sludge retention time, then after settling phase, the effluent was decanted from the reactor by a decanting pump at the end of settling phase. All equipment was connected to a programmable timer controller used to control different operating phases.

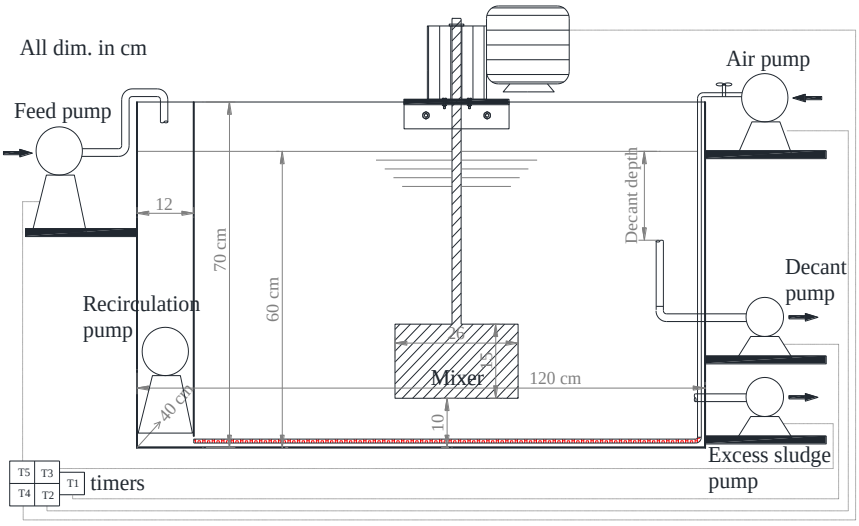

Figure (1) Schematic Diagram of ICEAS Pilot-Scale

2-2 ICEAS startup and experimental runs

The ICEAS reactor was inoculated with 100 liter seed biomass from Zenin conventional activated sludge wastewater treatment plant. The reactor with the seed sludge was continuously filled with raw wastewater and operated under operational cycle (Fig. 2) with hydraulic retention time of 15 hr. The startup continued with continuous monitoring of MLSS in reactor, without sludge wasting, till getting the desired MLSS, then sludge wasting occurred. Control the SRT value is achieved by excess sludge wasting in each cycle. The performance ICEAS was monitored after the startup period.

The reactor was operated for about six months to evaluate the effect of HRT on ICEAS performance with a same operational cycle presented in fig. 2 except influent flow was adjusted to maintain a desired HRT (15, 20 and 25 hrs.). The selection of this range of HRT was based on the literature (Metcalf and eddy; Ouyang and Juan1995; Mahvi et al., 2004; Aghapour et al., 2013).

The system is operated for about two months in each HRT. A gradual transition between two successive HRT was achieved in period of 10 days. The performance of ICEAS was monitored throughout the operation period.

During the operation period, the operational cycle was 6 hr, in each cycle of all three HRT runs. Figure 2 shows the ICEAS cycle details. Table 1 shows the different operational parameters for the three HRT runs.

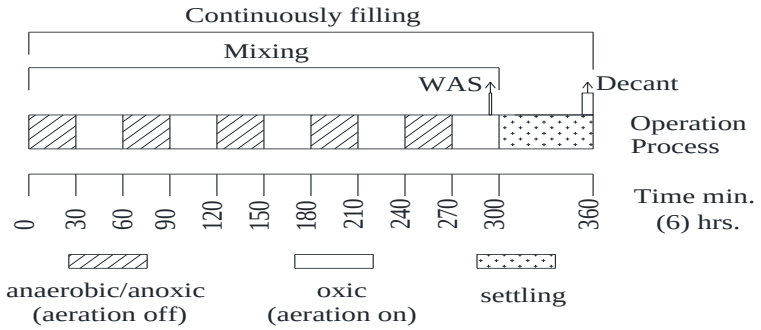

Figure (2) Operational cycle of ICEAS during start-up and experimental runs

Table (1), operational parameters of three HRT experimental runs

Experimental run HRT, hrs.	15	20	25
Feeding flow rate, L/d	460	345	278
Decant volume in each cycle, L	115	86.25	69.5
Volume Exchange Ratio in each cycle (VER, %) or decant volume/reactor volume	40	30	24
SRT, d	10-15	12-15	15-18
MLSS, mg/L	2706 ±283	2503 ±258	2360 ±107
SVI, ml/g	110±11	94±15	69±7

2-3 Wastewater characteristics

Municipal wastewater from Abu Rawash wastewater treatment plant was used in this study. The raw wastewater was examined two times per week. During this study, the ambient temperature was varied between 19 and 41 ^{0}C and pH was 7.0 to 7.8. Table 2 summarizes the characteristic of raw wastewater that was used during the three HRT runs.

Table 2, Characteristic of raw wastewater during experimental runs

Items	*Average (mg/L)±SD*
COD	330±55
BOD_5	175±28
TSS	169±35
NH_4-N	21.1±4.4
NO_2-N	0.0±0.0
NO_3-N	0.0±0.0
TN	38.1±6.3
TP	3.6±1.9

2-4 Analytical methods

Influent and effluent samples were taken two to three times per week. At the end of the settling phase, effluent samples were collected. The influent and effluent samples were analyzed for total suspended solid (TSS), total chemical oxygen demand (COD), total biochemical oxygen demand (BOD_5), ammonia (NH_4-N), nitrate (NO_3-N), nitrite (NO_2-N), total nitrogen (TN) and total phosphorus (TP). Also, other samples were taken at the end of last aerobic phase for analyzing the mixed liquor suspended solid (MLSS), mixed liquor volatile suspended solid (MLVSS) and sludge volume index (SVI). The samples for all analytical parameters were measured according to Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

3. RESULTS AND DISCUSSION

3-1 Effect of HRT on organic matter and solid removals in ICEAS pilot plant

To study the effect of HRT variation on the ICEAS performance in terms of COD, BOD_5 and TSS removal, HRT range of 15, 20 and 25 hrs were studied. Other operating conditions were SRT 10 days, cycle period was 6 hours. Figure 3 presents the ICEAS pilot plant performance in term of COD, BOD_5 and TSS removal percent; however, figure 4 shows the COD, BOD_5 and TSS effluent concentrations.

The COD removal was 96.43±0.34, 96.80±0.35 and 96.72±0.44%; BOD_5 removal was 97.33±0.31, 97.50±0.23 and 97.19±0.30%; TSS removal was 96.90±0.29, 96.72±0.52 and 96.25±0.40 % at HRTs of 15, 20 and 25 hrs respectively.

The effluent COD, BOD and TSS were 11.54±2.55, 10.50±1.83 and 11.02±1.77 mg/L for COD; 4.6±1.1, 4.5±0.8 and 4.9±0.5 mg/L for BOD_5; 5.4±1.3, 5.6±2.1 and 6.2±0.7 mg/L for TSS at HRTs of 15, 20 and 25 hrs respectively.

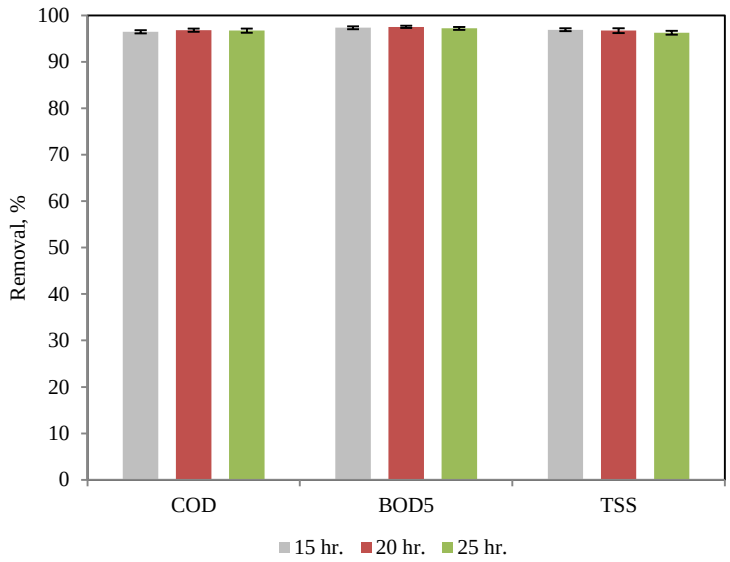

Figure (3) Effect of HRT variation on ICEAS performance in terms of COD, BOD_5 and TSS removal

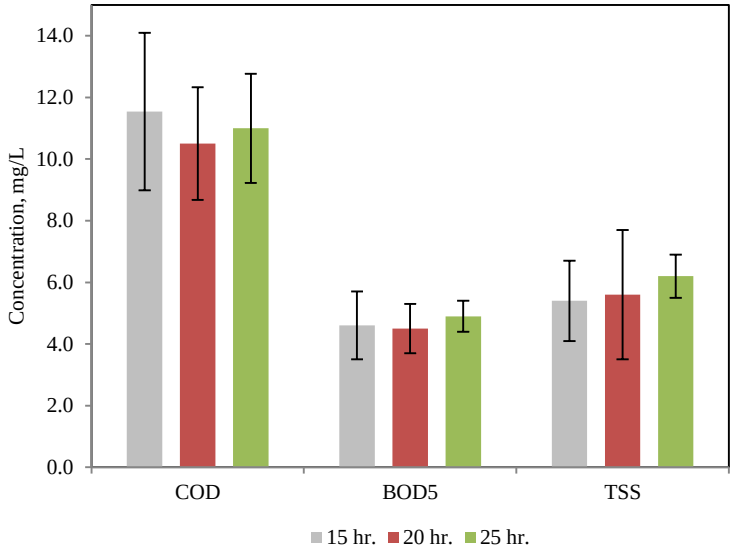

Figure (4.), Final effluent of COD, BOD_5 and TSS of ICEAS as a function of HRTs

Increasing HRT from 15 to 20 hr did not significantly affect the ICEAS performance in terms of COD, BOD_5, and TSS (P>0.05, one-way ANOVA by SPSS V25). Same observation was reported by Mahvi et al, (2004). Hence from technical and economical point of view, HRT of 15 hr is considered the optimum hydraulic retention time for organic matter and solid removals by intermittent cycle extended aeration system (ICEAS). It should be noted that under HRT of 15 hr operating conditions, the final effluent quality was 11.54±2.55, 4.6±1.1 and 5.4±1.3 mg/l for COD, BOD_5, and TSS which is amply meet the local regulation of class A treated wastewater (ECP 501/2015) for unrestricted reused applications.

3-2 Effect of HRT on ammonia and total nitrogen removals in ICEAS pilot plant

To study the effect of HRT variation on the ICEAS performance in terms of NH_4-N and TN removal, HRT range of 15, 20 and 25 hrs were studied. Other operating conditions were SRT 10 days, cycle period was 6 hours. Figure 5 presents the ICEAS pilot plant removals efficiency in terms of ammonia and total nitrogen removals. The NH_4-N removal was 96.79±0.60, 97.48±0.27 and 97.22±0.46% at HRTs of 15, 20 and 25 hrs. respectively. However, TN removal was 71.04±3.94, 79.13±2.30 and 86.06±3.12% at HRTs of 15, 20 and 25 hrs respectively.

Figure 6 presents the ICEAS pilot plant effluent concentrations in terms of NH_4-N, TN and NO_3-N. The effluent NH_4-N was 0.72±0.2, 0.55±0.09 and 0.53±0.15 mg/L for hydraulic retention times of 15, 20 and 25 hrs. respectively.

The effluent TN was 11.68±2.99, 7.90±1.52 and 5.14±1.89 mg/L for HRTs of 15, 20 and 25 hrs. respectively.

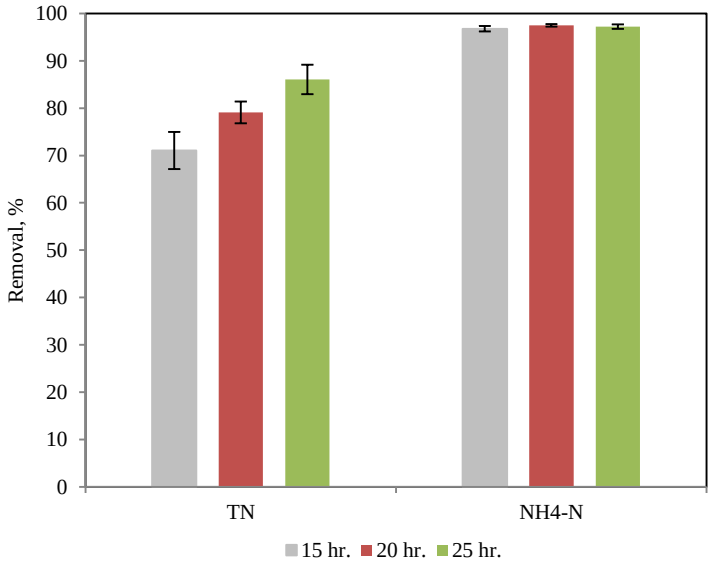

Figure (5) Effect of HRT variation on ICEAS performance in terms of TN and NH_4-N removal

The results showed that increasing HRT from 15 to 20 hr did not significantly affect the ICEAS performance in terms of NH_4-N removal (P>0.05, one-way ANOVA by SPSS V25). This could be ascribed to the long retention time as well as the temperature. The average temperature during operation period was 30 ^{0}C. Zhang et al., (2009) reported that the increase of temperature has a significant effect on the nitrification process.

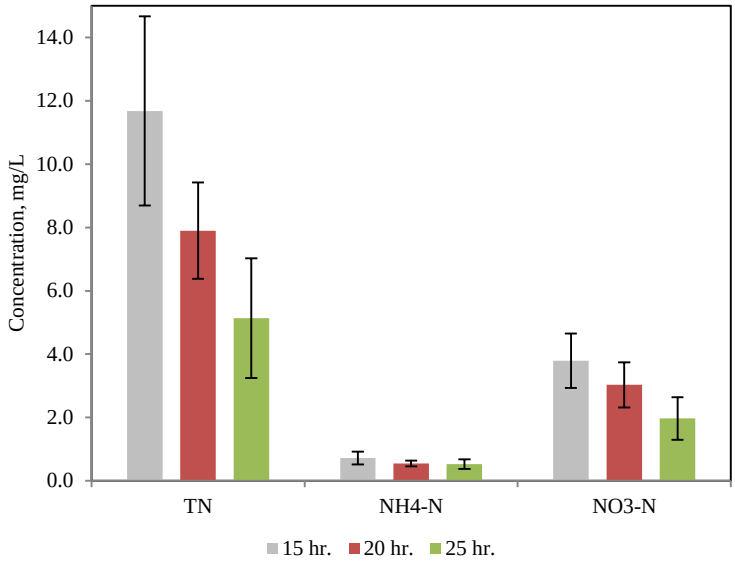

Figure (6), Final effluent of TN, NH_4-N and NO_3-N of ICEAS as a function of HRTs

However, increasing HRT from 15 to 20 hr significantly affect the ICEAS performance in terms of TN removals ($P<0.05$, one-way ANOVA by SPSS V25). Higher nitrogen removals were observed at HRT of 20 and 25 hrs where effluent of TN concentrations was 7.9 and 5.1 mg/L which is complying with the international regulations (U.S. EPA, 2004; U.S. EPA, 2012). However, at HRT of 15 hr the effluent quality in terms of TN concentration was 11.7 mg/L, which is higher that the international regulations of TN < 10 mg/l. The higher TN removal (denitrification) of the system could be ascribed to the availability of organic source due to the continuous inflow of wastewater and intermittent aeration (Mahvi et al., 2004). Mahvi et al., (2004) reported that TN removal was 85, 70 and 58% at HRTs of 16.7, 14 and 12.4 hrs respectively on ICEAS. TN removal was 65% and 71% at HRTs of 12 and 18.4 respectively Ouyang & Juan (1995). Ghehi et al., (2014) reported that TN removal was less than 88.3% at HRT of 20.8hr.

3-3 Effect of HRT variation on total phosphorus removal in ICEAS pilot plant

Variations of TP removal at different HRTs (15, 20 and 25 hrs.) are shown in figure 7. Figure 8 presents the average ICEAS pilot plant effluent concentrations in term of TP.
The effluent TP was 0.7±0.3, 0.9±0.6 and 1.1±0.9 mg/L at HRTs of 15, 20 and 25 hrs. respectively. The TP removal was 78.4±3.2, 77.2±5.4 and 72.0±5.1% at HRTs of 15, 20 and 25 hrs respectively.
Increasing HRTs in ICEAS from 15 to 20 hrs did not affect the TP removal ($P>0.05$, one-way ANOVA by SPSS V25). However, increasing HRT to 25 hrs significantly decreased the TP removal ($P<0.05$, one-way ANOVA by SPSS V25).

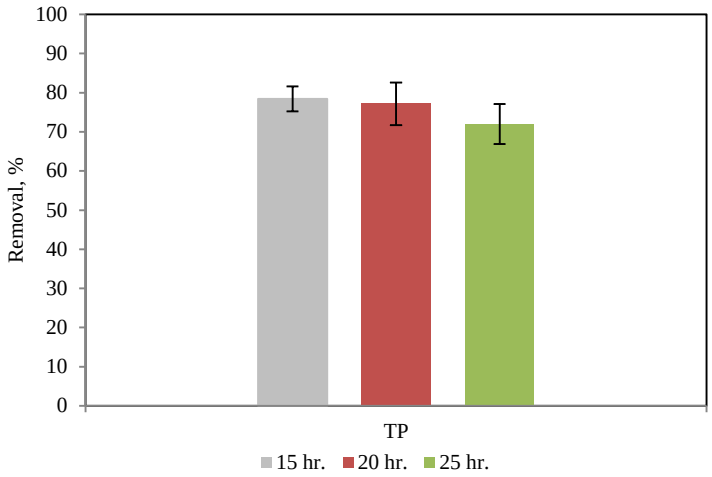

Figure (7) Effect of HRT variation on ICEAS performance in terms of TP removal

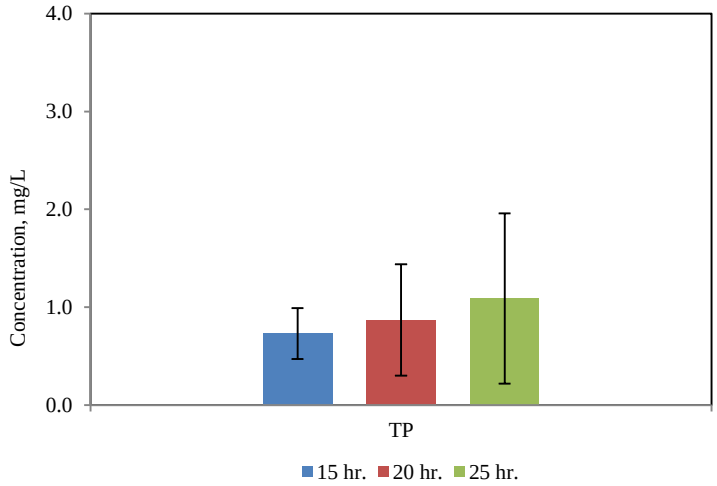

Figure (8), Final effluent of TP of ICEAS as a function of HRTs

This could be interpreted by considering the phosphorus removal mechanism. The phosphorus release occurs in anaerobic phase after nitrate depletion by POAs, resulting in an increase of phosphorus concentration at the end of anaerobic phase. Subsequently, in aeration phase, phosphorus uptake occurred by PAOs. Then phosphorus removal is accomplished by wasting the PAOs from the system (Metcalf and Eddy, 2014). Intermittent aeration in ICEAS provide multi anoxic/ oxic conditions and there is no real anaerobic phase in the system. So, anoxic phases support phosphorus and nitrogen removals.

Phosphorus is released in each anoxic period after depletion of nitrate, and the phosphorus uptake occurred in each subsequent oxic period. Higher phosphorus removal is observed in HRT of 15 hrs, due to shorter HRT that provide higher organic load on the ICEAS pilot scale.

Li et al., (2008) reported that the TP removal was 76% in ICEAS Wafangdian WTP. Ghehi et al., (2014) applied intermittent aeration in ICEAS and achieved TP removal of 81.9% at HRT of 20.8hr. Ouyang and Juan (1995) reported that ICEAS achieved TP removal of 68 % at HRT of 12 and 18.4 hrs while it was 27 and 49% at HRTs of 8.8 and 5.6 hrs. respectively.

4. Conclusions

A pilot scale was used, to study the effect of HRT (15, 20 and 25 hrs.) on ICEAS performance in terms of organic matter, total suspended solid, and nutrient removals. The conclusions of this study are summarized in the following clauses:

- The performance of ICEAS generally, proportional with HRT up to 20 hr. then fixed, so 20 hr is the lowest HRT to achieve optimum performance
- For COD, BOD_5 and TSS removals, the ICEAS performance was stabilized from 15 hr.
- For TP removal, the ICEAS performance was stabilized from 20 hr.
- For TN removal, the ICEAS performance was stabilized from 25 hr.
- So, the performance could be ensured in the best behaviour with HRT 20 hr.
- Under the optimum HRT of 20 hours, effluent concentrations in terms of COD, BOD_5 and TSS, TN, NH_4-N and TP were 10.50 ±1.83, 4.5±0.8, 5.6±2.1, 7.90±1.52, 0.55±0.09 and 0.9±0.6 mg/l which is complying with the local and international regulations.

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