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Upgrading the Performance of Urban Wastewater Facultative Ponds by changing to Attached Baffled Process

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ABSTRACT: This study aims at evaluating the improved facultative ponds performance in pilot scale. Wastewater has been collected from primary settling basins of Ahvaz wastewater treatment plant. Treatment efficacy of the four systems (three systems in parallel with a control system) has been evaluated over a period of 12 months at various hydraulic retention times (HRT) and organic loading rates (OLR). There has been no baffle and no attached growth media (AGM) in the control system (S_0), while other three systems (S_2, S_3, and S_4) have been equipped with different numbers of baffles and AGM packages, containing the mineral shells. Results show that efficiency of BOD_5 removal for S_0, S_2, S_3, and S_4 are 53.4%, 60.8%, 64.7%, and 67.6%, respectively, while for COD these rates alter to 28.1%, 37.7%, 45.8%, and 50.1 % and of coliform to 66.7%, 76.6%, 80.7%, and 83.4%. Filtered BOD_5 in the effluent of S_0, S_2, S_3, and S_4 is 32.5, 27.6, 24.6, and 22.3 mg/l, respectively and 60.2, 52.1, 47, and 44.3 mg/l for TSS. Also the 10-day HRT has been optimum among applied HRTs. As such, attached growth-baffled ponds function better than conventional ones, making the technique, examined in the present paper a low-cost process to establish new wastewater treatment plants or upgrading the existent WSPs, especially in case of warm areas of southwestern Iran.

Keywords: natural treatment, pond, HRT, warm areas, organic material

INTRODUCTION

Wastewater management in developing countries is increasingly becoming a priority. Conventional wastewater treatment processes such as activated sludge, used in most industrialized nations, are not likely options in many developing countries to provide environmental and public health protection (Olukanni, 2013), as they have difficulty sustaining the required energy and chemical consumption needed for successful operation of technologies used in conventional wastewater treatment plants (Spinosa et al., 2017). This is further intensified by accelerating urbanisation, inadequate wastewater management and disposal, and implementation of sophisticated treatment technologies that are highly centralised (Libralato et al., 2012). Waste Stabilization Ponds (WSPs) are among the best treatment options, particularly in developing countries and warm climates (Mara, 2003). In developed countries such as Canada with a cold climate, WSPs continue to be the most common wastewater treatment solution (Colin et al., 2015). In the US, more than 50 percent of

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wastewater treatment plants are WSPs (Long et al., 2017). Iran is a vast country with different climate types. Khuzestan Province, southwest of the country, has a warm climate, while its villages lack wastewater treatment plants. As a low-cost system, based on natural methods, WSPs could be an attractive option in Khuzestan. In recent years, many studies of stabilisation ponds have focused on improving treatment efficiency (Rinhofer & Smith, 2010; Babu et al., 2011; Faleschini et al., 2013; Moumouni et al., 2015; Ouedraogo et al., 2016; Khan et al., 2017; Dias et al., 2017; Bassuney & Tawfik, 2017 ; Sasani et al., 2017). Two effective methods include placing baffles and attached growth media (AGM) in the ponds for two reasons: (1) Baffles decrease the short circuiting phenomena that increase real retention time (Shilton, 2006; Babu et al., 2011; Park et al., 2014). In addition, the area of the pond's bottom and side walls creates a suitable environment for microorganism growth and better organic matter removal (Sah et al., 2011). (2) Placing fixed media in the pond like baffles provides a surface for microbial film growth that makes it tolerant against high organic loading rate (Zhao & Wang, 1996; Rakkoed et al., 1999; Alsaed et al., 2011; Moumouni et al., 2015). Researchers have studied the baffles' effect on WSP performance (Abbas et al., 2006; Babu et al., 2011; Olukanni & Ducoste, 2011; Khan et al., 2017), with some of them evaluating the efficiency of attached growth waste stabilization ponds in wastewater treatment (Zhao & Wang, 1996; Alsaed et al., 2011; Moumouni et al., 2015). Few studies have investigated the effect of both baffles and AGM on facultative pond performance; therefore, the main objective of this study is to investigate the simultaneous effects of the number of baffles and amount of mineral shells like AGM on the performance of secondary facultative ponds.

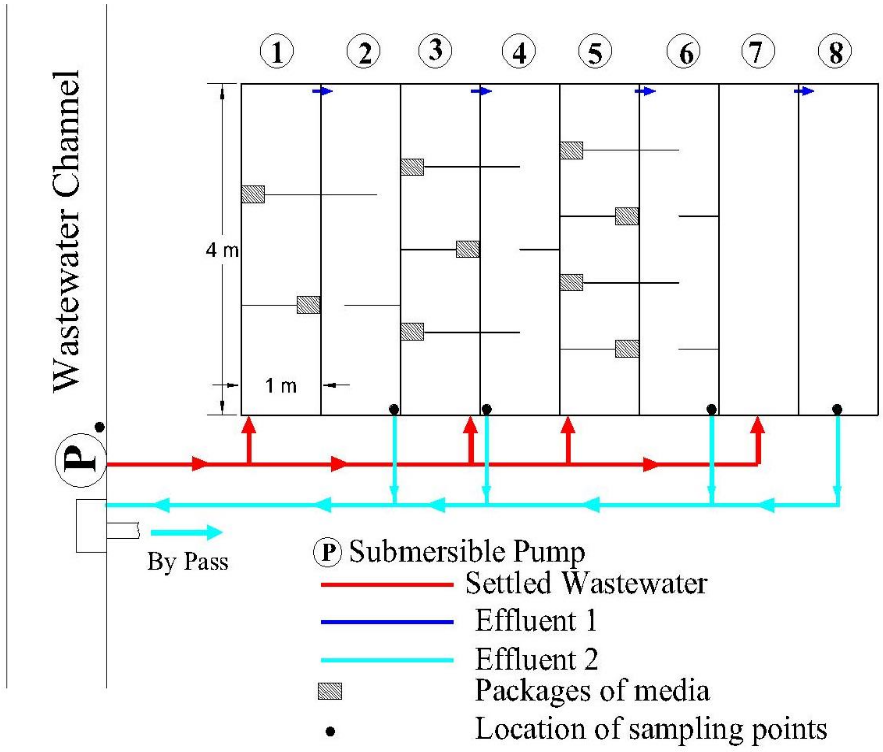

Fig. 1. Plan and configuration of the pilot

MATERIALS AND METHODS

As shown in Figure 1, this study's pilot consisted of a control system (S_0) along with three other systems (viz. S_2, S_3, and S_4). S_0 included two serially-connected facultative ponds, the dimensions of which equaled to 4m×1m×1m and 4m×0.8m×1m, respectively. The other systems had the same size and dimensions as S_0 but two, three, and four baffles were installed in S_2, S_3, and S_4, respectively. Wooden vertical baffles, installed in the pond, achieved a baffle to pond width ratio of 70%. As far as sealing the ponds is concerned, there are commonly used sealers, classified into three major categories: synthetic, cement, and natural sealers (EPA, 2011). In the present study, a cement sealer covered the inner surface of the pilot, followed by a synthetic sealer of asphaltic component, served as the final lining. Mineral shells with a specific surface area of about 100 m^2/m^3 and average diameter of 5 Cm served as AGM, placed in plastic boxes. In the first pond of each baffled system, three boxes were installed over each other beside each baffle, as Figure 1 indicates. To evaluate the systems' performance in removing pollutants, settled wastewater entered each system, its flow pace being 0.6 m^3/d. During the first month of the study, the ponds' situation got continuously monitored in terms of wastewater color and dissolved oxygen concentration (DO). When the wastewater color turned green and DO concentration surpassed 1.5 mg/l, the formation of photosynthesis algae was confirmed. Under this condition, grab samples were taken from the effluent of all systems at 10 o'clock (three times a month) so that important quality factors like five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), total coliform, ammonia-nitrogen (NH_4-N), and total phosphate (TP) could be tested. During the second, third, and fourth months, the flow pace rose up to 0.75, 1, and 1.2 m^3/d, respectively. Furthermore, the first phase spanned the first fourth months (i.e., from March to June).

The same flows repeated during the second phase from the fifth to the eighth months (i.e., from July to October), though with a descending trend. Similarly, in the third phase, lasting from the ninth to the twelfth months (or from November to Febrerary), flows repeated as in the second phase. Figure 2 shows the study's experimental phases with variations in wastewater temperature, flows, and OLRs, applied to the systems during the sampling period with Figure 3 summarizing average values of the main meteorological parameters (sunshine hours, air temperature, and wind speed) recorded for the investigated region. According to this figure, the highest temprature belonged to July (39.3 ˚C), while December, January, and Fabruary had the coldest months with an average temperature of 14˚C. The trend for changes in sunshine hours was similar to that of temperature; as such, the maximum and minimum values belonged to August and January with 352.7 and 167.5 hours, respectively. Wind speed, compared with temperature and sunshine hours, had little fluctuation with the average value being reported as 116.5 cm/s and the maximum and minimum values belonging to June and October with 152 and 90.7 cm/s, respectively. All experiments were completed based on standard methods (APHA, 2005) and XLSTAT software, (v. 2016.5) analyzed the data. The student's t test determined statistical difference, showing a level of significance equal to 95% with an error rate of less than 5% being acceptable (p-value <0.05).

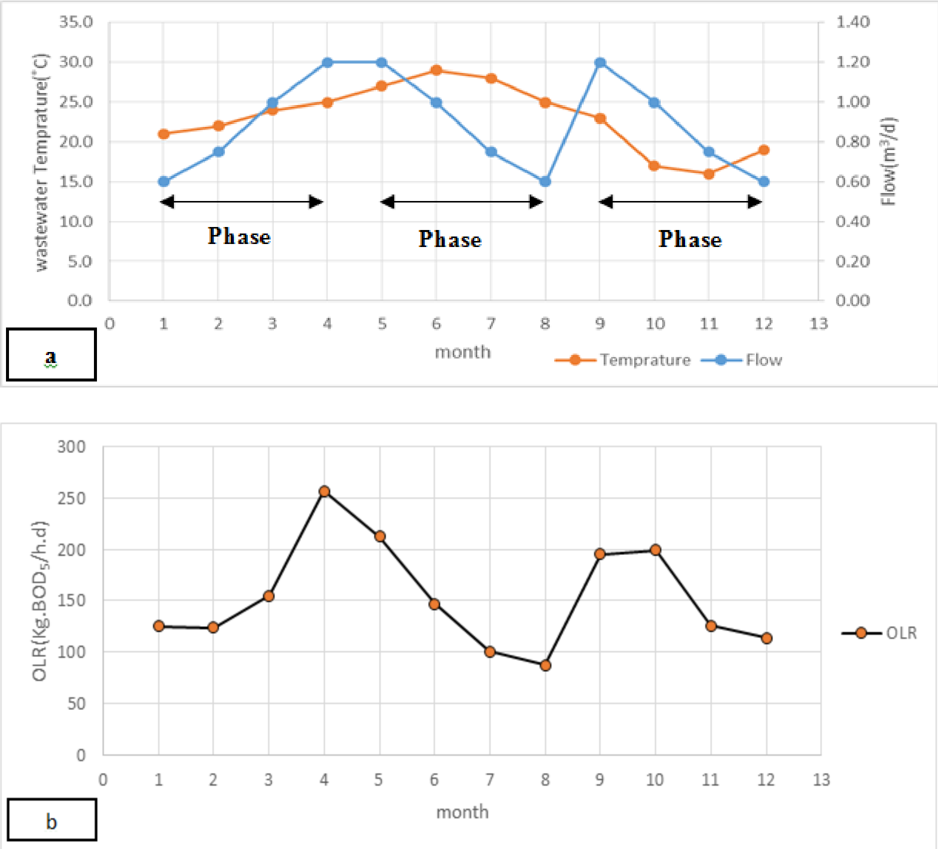

Fig 2. Flow and wastewater temperature (a) and organic loading rate (OLR) (b) during the sampling period

The pilot was operated in three phases; each, lasting for four months. Phase1: the first fourth months, phase2: from the fifth to the eighth month, and phase3: from the ninth to the twelfth month. In each month, settled wastewater entered each system with a fixed flow and during each phase, wastewater flow altered as shown in Fig2.a

Table 1. Quality of settled wastewater in sampling period

Row	Parameter	unit	March (Month1)	April (Month2)	May (Month3)	June (Month4)	July (Month5)	August (Month6)	September (Month7)	October (Month8)	November (Month9)	December (Month10)	January (Month11)	February (Month12)	Average	Standard deviation
1	BOD_5	mg/l	167	132	124	171	142	118	107	117	103	160	134	152	135.6	19.0
2	COD	mg/l	274	236	172	252	218	168	155	174	159	290	235	254	215.6	41.7
3	TSS	mg/l	86	62	63	48	55	81	75	69	78	84	63	71	69.6	9.6
4	TP	mg/l	4.8	4.4	3.9	4.3	4.6	3.8	4.2	4	4.5	4.9	4.2	4.7	4.4	0.3
5	TKN	mg/l	35	33.4	29.7	31	32	28	30	36	37	28	35	32	32.3	2.5
6	TC	MPN/100ml	8.5×10^{12}	8.7×10^{12}	7.9×10^{12}	7.8×10^{12}	8.2×10^{12}	8.8×10^{12}	7.6×10^{12}	7.1×10^{12}	7.8×10^{12}	8.9×10^{12}	7.3×10^{12}	8.6×10^{12}	7.8×10^{12}	5.1×10^{11}
7	pH	-	7.7	7.3	7.2	7.8	7.5	7.8	7.3	7.6	7.2	7.5	7.8	7.6	7.5	0.2

Table 2. Variation of DO and pH in the systems' effluent during the experimental phases

system	Phase1		Phase2		Phase3	
	DO(mg/l)	pH	DO(mg/l)	pH	DO(mg/l)	pH
S_0	3.39	8.61	4.22	8.79	2.69	8.27
S_2	3.91	8.88	4.85	8.96	3.04	8.43
S_3	4.12	8.98	5.02	9.01	3.24	8.55
S_4	4.31	9.01	5.11	9.06	3.42	8.59

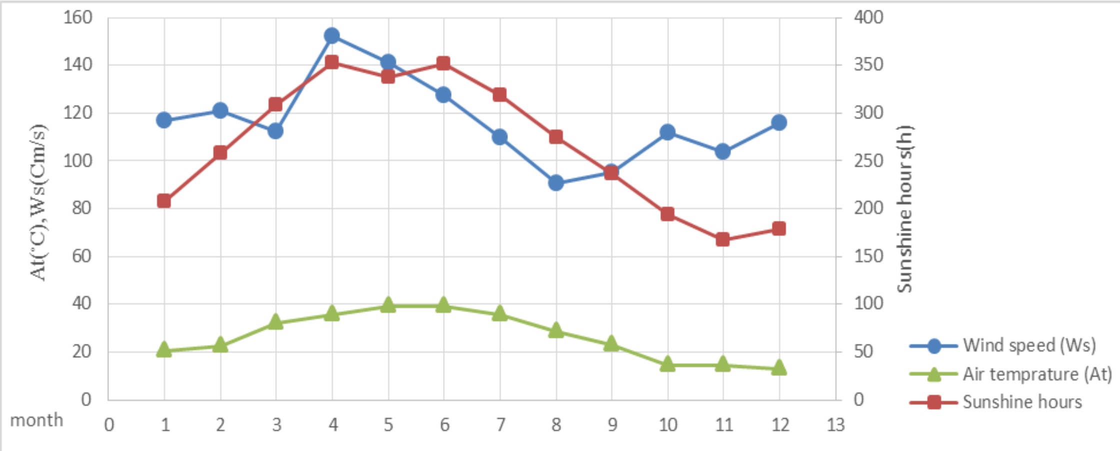

Fig. 3. Meteorological parameters during the sampling period

RESULTS AND DISCUSSION

According to Figures 4-6, comparison of the effluents of four systems shows that the highest values for pollutant parameters are in the effluent samples, obtained from S_0 (with the lowest HRT). The average BOD_5, COD, and TSS values in the effluent of S_0 were recorded within the range of 48-107, 105-210, and 67-132 mg/L, respectively. The lowest pollutant parameters values belonged to S_4, wherein the average values of BOD_5, COD, and TSS in the effluent ranged within 28-80, 70-160, and 52-99 mg/L, respectively.

Statistical evaluation of the data, obtained for removal efficiencies related to BOD_5, COD, and TSS, showed that the presence of several baffles and AGM had a significant effect ($p < 0.05$) on purification efficiencies of the settled wastewater. The average BOD_5, COD, and TSS removal turned out to be the highest in S_4 (67.6%, 72.3%, and 37.5%, respectively). In addition, it was also proven statistically that the removal efficiencies decreased by redducing attached growth area, reaching 50.3% for BOD_5, 55.1% for COD, and 15.1%, for TSS in S_0. Fig 4 shows that the average BOD_5 for S_0, S_2, S_3, and S_4 during the-12 month period was 66.1, 55.7, 50.0, and 45.8 mg/l, respectively, which is consistent with the observations in Shilton study (2006), stating that at least two baffles were recommended in each pond. Previous studies confirmed that adding baffles to a pond provided more area for bacteria and algae growth which improved the efficiency of organic matter removal (Abbas et al., 2006; Babu et al., 2010). In this study, adding mineral shells as a low-cost AGM helped the baffles provide more area for attached bacteria and algae growth. According to Fig 5, the average COD concentration in the effluents of S_0, S_2, S_3, and S_4 was 169.2, 145.7, 129.2, and 117.9 mg/l, respectively. By adding baffles and mineral shells to the ponds, COD removal efficiency increased from 27.2% (in S_0) to 50.1 % (in S_4). Table 2 shows the variation in pH and DO for all systems throughout three experimental phases. The average pH increased from 8.56 (in S_0) to 8.88 (in S_4), due to the predominance of algae photosynthesis over respiration. According to Table 2, DO, like pH, increased from 3.45 to 4.28 mg/l (S_0 to S_4), possibly due to longer HRTs of baffled ponds, compared to the conventional ones, as they enhanced algae growth by reducing cell washout. Algal photosynthesis removes carbon dioxide (CO_2) from the liquid, thus reducing carbonic acidity and increasing pH and DO. Previuos studies confirm the dependency of pH and DO on HRT (Assunção & Von Sperling, 2013; Da Silva et al., 2010). The increase in DO from S_0 to

S_4 comes from better organic matter removal as explained above.

Similar results were obtained for coliform removal efficiencies in the four systems. The statistical evaluation of the data showed that the attached growth area had a significant effect ($p < 0.0001$) on coliform removal rate, though absolute values for removal rates were much lower than those, obtained for BOD_5, COD, and TSS.

The purification efficiency of the systems could be assessed on the basis of criteria given in the Iranian Department of Environment (DOE), whose control guidelines set 150 and 30 mg/l for TSS and FBOD (filtered BOD_5), respectively, as standard effluent of the WSPs to be discharge to surface water. According to Fig 6, the mean TSS of S_0, S_2, S_3, and S_4 effluent during the sampling period was 60.2, 52.1, 47, and 44.3 mg/l, respectively; therefore, concentrations of TSS in all systems' effluent were below the permissible limit (150 mg/l). Increased baffles seemingly increased HRT and enhanced TSS removal consequently. (Babu et al., 2011; Alsaed et al., 2011). Obviously, organic nature of TSS in the ponds effluent differs with suspended organic material in raw sewage, as these suspended particles are algae cells and, if they enter surface water, they are immediately diffused and consumed by zooplanktons, hence increasing the oxygen concentration. When used in agricultural applications, these algae cells act as fertilizers and increase organic material and water retention capacity of the soil (Von Sperling, 2007). According to Figure 7, the concentration of FBOD in S_0, S_2, S_3, and S_4 was 32.5, 27.6, 24.6, and 22.3 mg/l, respectively. With the exception of S_0, the average FBOD for all systems' effluent was below the permissible limit (30mg/l). Fig.8 illustrates FBOD concentration, obtained from all systems with different HRTs. According to this figure, in a HRT of 6.3 days the FBOD in all systems' effluent exceeded 30 mg/l, indicating that the HRT was insufficient for organic matter removal. The corresponding OLRs of these three situations were 195, 213, and 257 Kg.BOD_5/h.d. At one case for the months, the HRT of which was 7.6 days, FBOD was above the permissible limit; therefore, only HRTs of 10.1 and 12.7 days, produced effluents with acceptable FBOD. The range of OLR applied for these HRTs was 87-126 Kg.BOD_5/h.d. Results from this study agree with the results, reported by Orumieh et al. (2015), from their evaluation of the efficiency of a few WSPs in Iran under different climatic conditions. There, they showed that at a loading rate below 200 KgBOD_5/h.d, removal efficiency in secondary facultative ponds ranged between 60% and 70%, while the concentration of BOD_5 dropped below 80 mg/l in proportion to HRT.

Figure 9 shows the coliform concentrations in the effluent of all systems during sampling period. According to this figure, an increased number of baffles and amount of AGM improved coliform removal, e.g. for S_0, S_2, S_3, and S_4, the removal was 66.7%, 76.6%, 80.7%, and 83.4%, respectively. Although these values are notable for facultative ponds, they were still not sufficient for discharging the effluent to surface water. To achieve an effluent with accepatable microbial standards, maturation ponds can be used, which goes beyond the scope of this study. In baffled attached growth WSPs, factors such as filtration, adsorption, aggregate formation, and predators contribute to passive aerobic conditions, and the attached growth surface area may be responsible for higher rates of coliform removal (Mara & Johnson, 2006; Johnson et al., 2007).

Results from this study proved that by increasing the area for microbial attached growth, pollutant removal increased, which was in agreement with the results of Zhao

& Wang, (1996), who stated that, increased AGM density in a pond results in better pollutant removal. The higher density and specific area (1234 m^2/m^3) of AGM, applied in their work, in comparison to the present study, led to better organic matter removal in that work. Althogh placing artificial AGM with high specific area in the ponds in real scale raised the construction costs considerably. Rakkoed et al. (1999) investigated the performance of AGM-containing WSPs with low specific area in the lab scale. For their study, they laid brick and plastic pecies at the bottom of the ponds. Using 20-day HRT, COD, and BOD_5 removal efficiency in an attached growth WSP turned out to be higher than that of a conventional WSP (7.4% and 2.7%, respectively), whereas the results obtained here for average BOD_5 and COD removal efficiency of S_4 were 14.2% and 22.8% more than S_0, respectively. The obtained results also agreed with those of Alsaed et al.'s study (2011), in which, the pilot consisted of four subsequent ponds: one anaerobic pond, two facultative ones, and one polishing pond. They installed rock-filter media in the facultative ponds and managed to increase faecal coliform removal from 99.89% to 99.96%, COD removal from 76% to 80.5%, and TSS removal from 72.7% to 77.3%. Results were consistent with the ones, obtained by Quali et al. (2012), who evaluated the effect of baffles in the performance of a maturation pond in real scale and showed that due to the presence of two baffles, the removal efficiency of coliform rose from 69% to 82%. They were also comparable with those of Mahapatra et al. (2013), according to whose research, the concentration and removal efficiency of TSS in the effluent of a facultative pond equipped with two baffles with 11.8 days HRT were 94 mg/l and 67.4%, respectively. Furthermore, these results were consistent with the ones, obtained by Babu et al. (2011), who evaluated three different configurations of 15 baffles in the performane of maturation ponds. TSS concentration for a baffled pond and a control pond were 25 and 55 mg/l, respectively. According to Moumouni et al. (2015) installing three baffles, which had waste plastic bottles fixed to them in order to increase the attached surface area, raised Escherichia coli (E.coli) removal by 8.7%, in comparison to an unbaffled pond. All these results confirmed that the introduction of baffles and AGM in the stabilization ponds improved the bacteriological performances and increased organic matter removal.

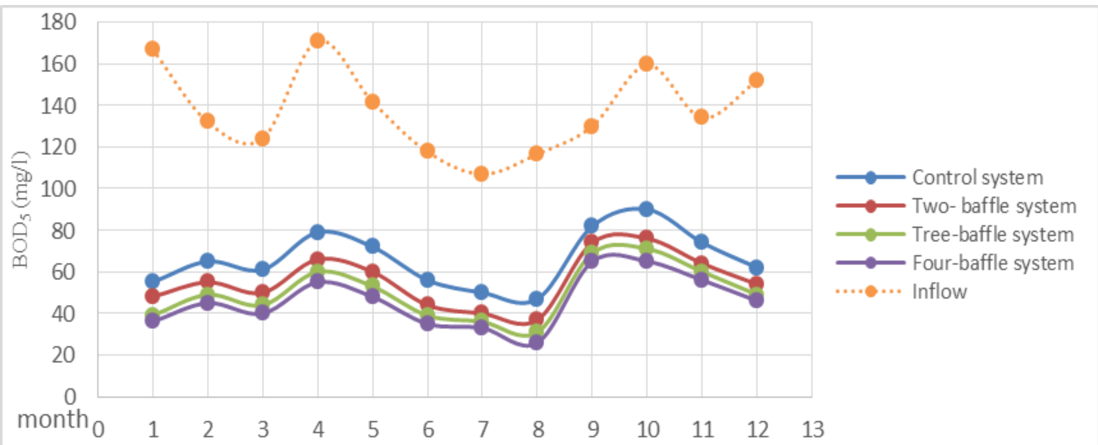

Fig. 4. BOD_5 of influent and effluent of the systems during the sampling period

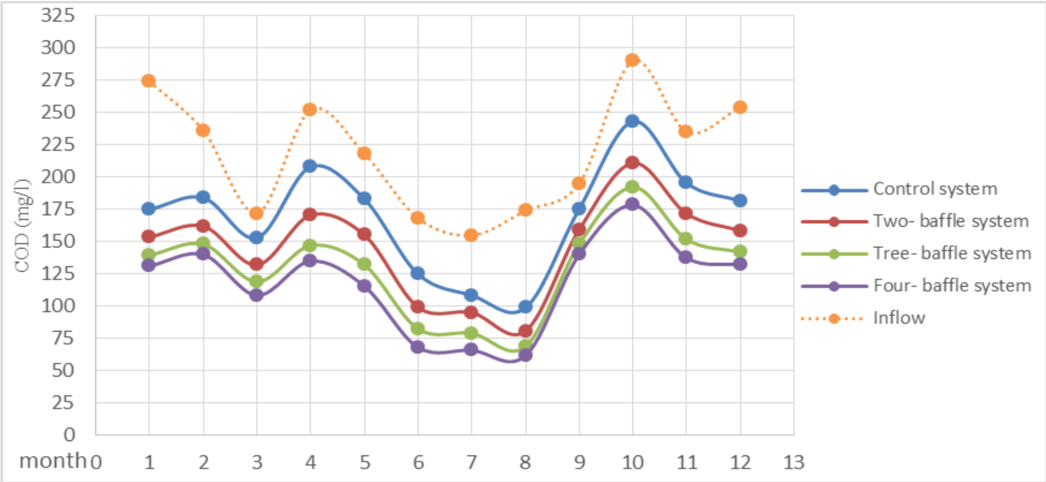

Fig. 5. COD of influent and effluent of the systems during the sampling period

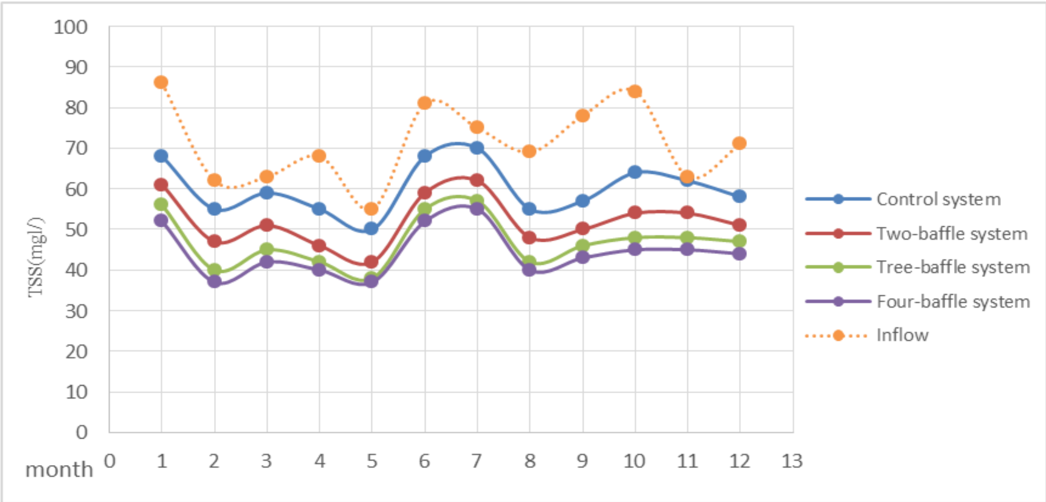

Fig. 6. TSS of influent and effluent of the systems during sampling period

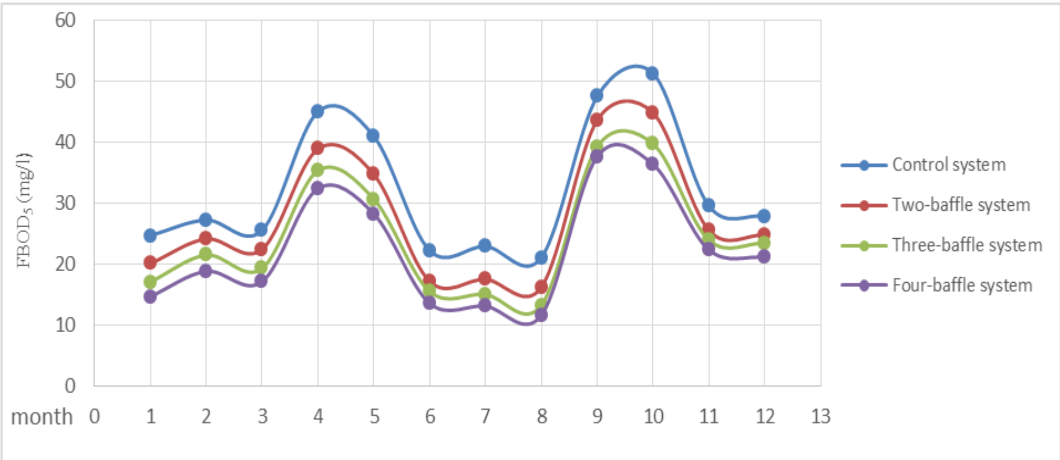

Fig. 7. $FBOD_5$ of effluent of the systems during the sampling period

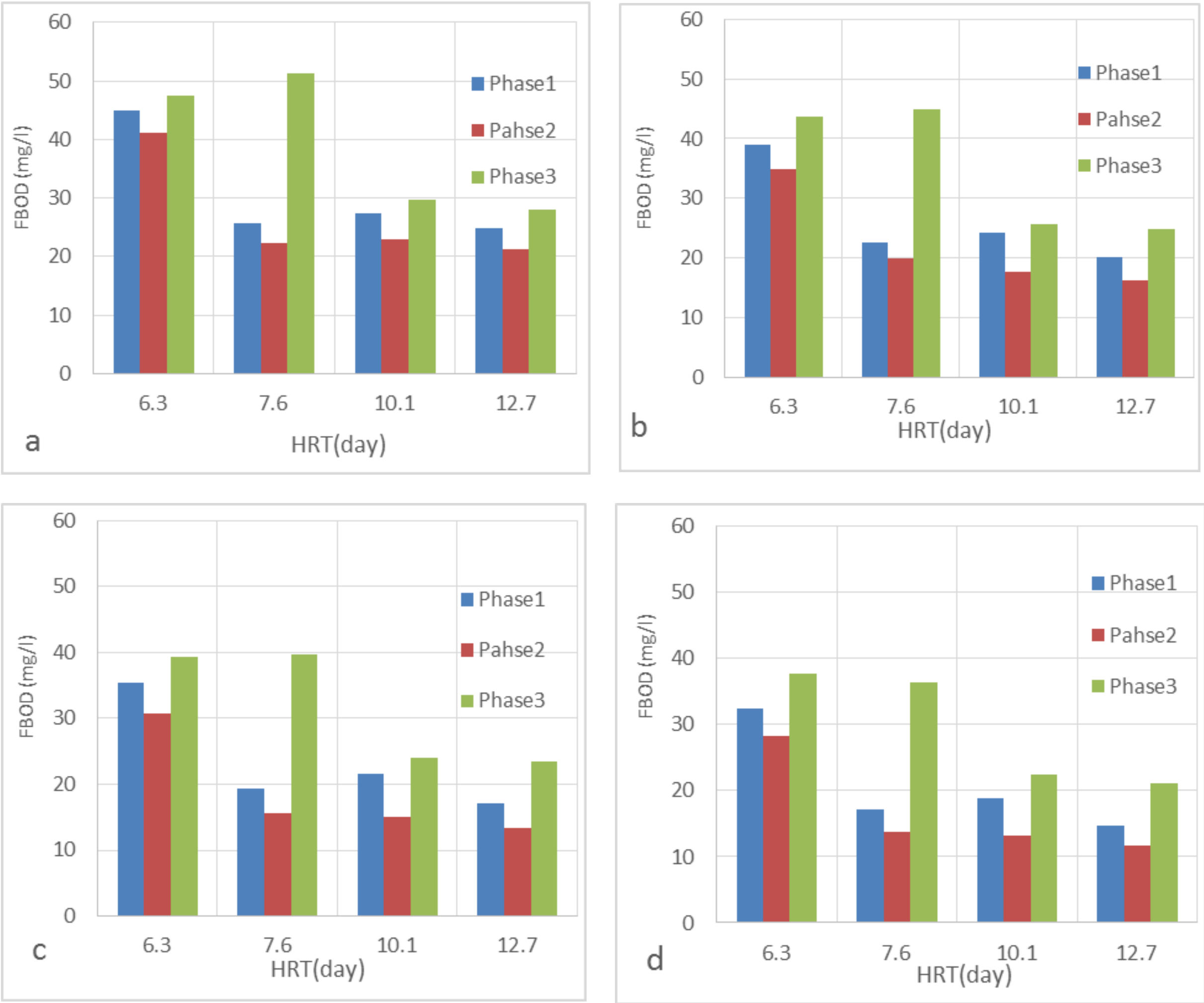

Fig. 8. Variation of filtered BOD_5 (FBOD) for effluent of (a) the control system, (b) two-baffle system, (c) three-baffle system, and (d) four-baffle system against Hydraulic Retention Time (HRT)

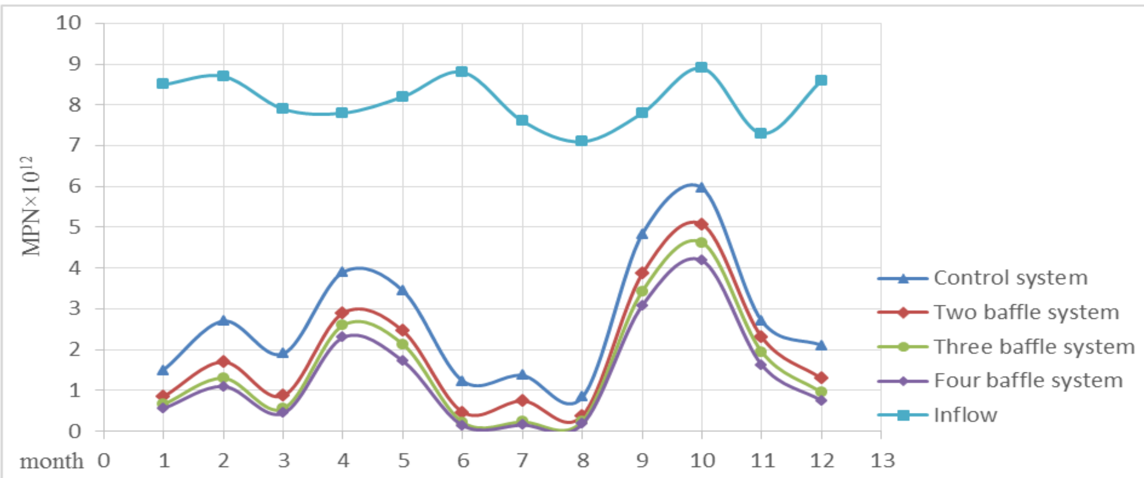

Fig. 9. Coliform concentrartion of both influent and effluent of the systems during the sampling period

CONCLUSION

The present work studied the effect of attached growth area on the performance of facultative ponds, located in Ahvaz (soutwesthern Iran), investigating the performance of three systems with different numbers of baffles and amount of mineral shells as AGM in parallel with a control system for a 12-month period and with regard to treating settled wastewater.

Results showed that the highest COD, BOD, TSS, and coliform removal efficiencies were 50.1%, 67.6%, 37.4%, and 83.4%, respectively, all obtained in S_4, i.e., the system with the maximum area for algae-bacteria biofilm growth. In addition, facultative ponds performance in organic matter removal, not only depended on OLR, but on HRT also. For this system, 10-day HRT was the optimum value among all applied HRTs.

This study supports the theory that baffles with mineral shells play an important role in removal of pollutants. A pretreatment unit such as a settling basin or septic tank, combined with attached growth baffled ponds, can be used as a low-cost process to either establish a new wastewater treatment plant or upgrade an existent WSP system, especially for rural areas of developing countries with warm climates, such as southwestern Iran.

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