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Performance evaluation of wastewater stabilization ponds in Yazd-Iran

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Abstract
Background: Yazd waste stabilization pond facilities consist of three stabilization pond systems, module 1, module 2 and module 3 that AWSP module 1 has started its operation. The existing facilities have had several problems in their operation. The objectives of this research were to evaluate the performance of stabilization ponds in wastewater treatment of the city of Yazd, due to several problems in their operation, and to prepare a scheme of its upgrading, if necessary.
Methods: During the period from December to June 2010, data analysis were carried out for both raw and treated wastewater.
Results: Results of these investigations showed that the average effluent concentrations of Biochemical Oxygen Demand 5 (BOD_5), Chemical Oxygen Demand (COD) and Suspended Solid (SS) taken from anaerobic pond and secondary facultative ponds of module 1 were 306.9, 135.18, 139.75 and 136.75, 69.025, 136.5 mg/L, respectively.
Conclusion: These results indicated that the effluent of the anaerobic pond of module 1 was complied with the Iranian treated wastewater standards for agricultural reuse in terms of BOD_5 and COD concentrations; hence the secondary facultative ponds could be changed to other primary facultative ponds in order to increase the capacity of wastewater treatment plant.
Keywords: Biological wastewater treatment, Stabilization pond, Yazd
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Introduction
Wastewater Stabilization Pond (WSP) is considered as the most appropriate system to treat the increasing flows of urban wastewater in tropical and subtropical regions of the world. WSPs are commonly used as efficient means of wastewater treatment relying on little technology and minimal, albeit regular maintenance. Their low capital and hydraulic loads have been valued for years in rural regions and in many countries wherever suitable land is available at reasonable cost (1-5). They generally consist of a series of ponds where the wastewater has around twenty days retention time and usually a depth from one to three meters depending on the type of pond (6). These ponds have been used for treatment of municipal, agricultural, and industrial wastewater. The primary function of anaerobic lagoons is stabilization and breakdown of the high concentrations of organic pollutants contained in wastewater and not necessarily production of a high-quality of effluents. Most often anaerobic lagoons are operated in series with facultative and aerobic lagoons (7,8). Although, stabilization ponds are effective methods of wastewater reclamation and reduction of the Biochemical Oxygen Demand 5 (BOD_5) and coliform as efficient, high concentrations Suspended Solids (SSs) exceeding 100 mg/L in their effluents is one of the major disadvantages of these systems (9,10). Several techniques are used to treat domestic wastewater. These can be classified into two groups: conventional and non-con-

ventional treatment plants. The former has high-energy requirements. The later is solely dependent on natural purification processes. The conventional systems of wastewater treatment include trickling filters, activated sludge systems, biodisc rotators, and aerated lagoons. The non-conventional systems, which are also called eco-technologies include constructed wetlands and WSPs. Among these technologies, the widely recommended ones for developing countries are the WSPs (11). Oxidation ponds are also called stabilization ponds or lagoons and serve mostly small rural areas, where land is readily available at relatively low cost (12). WSPs are biological treatment systems, the processes and operations of which are highly dependent on the environmental conditions, such as temperature, wind speed and light intensity which are highly variable, and any given combination of these environmental parameters is usually unique to a given location (13). There are many advantages of using this kind of biological treatment like ease of operation, low energy requirement, less equipment maintenance, and better sludge thickening. However, the effluent quality from fixed-film system is relatively poorer than suspended growth systems in terms of BOD_5 and SS (14). If pond systems are correctly designed and managed in order to cultivate anaerobic and aerobic bacteria and green micro-algae, then such systems will decompose water-borne organic wastes effectively and efficiently, and will help in reducing some of the problems associated with the treatment and disposal of wastewater. In addition, about 90% of the ponds in the United States are used in small communities with less than 10,000 residents and are very effective in wastewater treatment (13). The city of Yazd is located in the central part of Iran, with a population of around 900,000 people and many small and large industries. Municipal and industrial wastewater of this city is conducted to a wastewater treatment plant through sewer. The basic wastewater treatment process in Yazd is stabilization pond. However, due to inappropriate design and consideration of both biological process and physical aspects of the ponds, the existing facilities suffer serious malfunctioning problems. Hence, a program was developed during the period from December to June 2010 with a case study on the existing facilities. The main objectives of the program were to train the personnel to monitor, and evaluate the pond performance and effluent quality of the stabilization ponds, and to propose a scheme for upgrading and expanding WSPs, if necessary, depending on the results obtained. Similar programs have been developed in many parts of the world (3,15-17).

Methods

Site specifications

The wastewater treatment plant of Yazd is located in the north of the city, close to the main road of Yazd airport (Figure 1). The latitudinal location of the Yazd WSPs is about 34.08 N, the longitude is around 49.70 E, and the pond's altitude is 1710 m above sea level. Yazd treatment plant consists of three WSP systems as AWSP module 1 (M1), AWSP module 2 (M2) and AWSP module 3 (M3). The M1, M2 and M3 facilities are parallel with each other and AWSP module 1 have started their operation in 1993 and 2006, for the equivalent population of 25,000 and 80,000, respectively. As can be seen in Figure 2, the studied WSP systems are the same as classical pond configurations with anaerobic and facultative ponds. The studied wastewater treatment plants in Yazd have a pretreatment unit that includes screens followed by the WSP systems. Table 1 presents the physical and operational characteristics of the AWSP systems. The M1 AWSP comprises one Anaerobic Pond (AP) in parallel followed by a distribution tank that distributes the APs effluent into one parallel Primary Facultative Pond (PFP), followed by two Secondary Facultative Ponds (SFPs) in parallel (Figure 2). The treated wastewater of M1 facilities is used for agricultural reuse. As pointed out by Mara *et al* (18), the current reuse of wastewater for agricultural purposes is attractive to many local authorities, especially to those in water-scarce regions. It is known that agriculture is responsible for more than 80% of total world water consumption (19).

Sampling

This was a descriptive cross-sectional study carried out during 6 months including the cold-season months (from mid-January to mid-March) and warm-season months

Figure 1. Overview of treatment plant

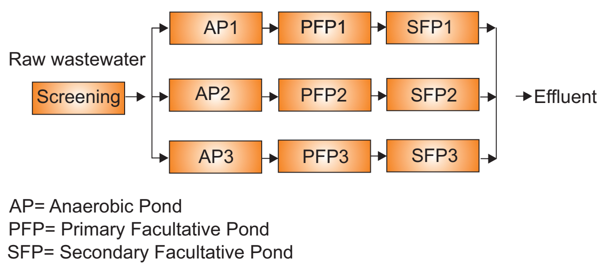

Figure 2. Schematic flow diagram for M1 AWSP

Table 1. Physical and operational characteristics of the M1 AWSP system

Parameter	AP	PFP	SFP
Hydraulic retention time (day)	5	4	4
The depth of the pool basin	5	5	5
Free height (m)	0.75	0.75	0.75
Area (m^2)	24617	43981	43981
Size Bottom of Ponds (m^2)	19015	39676	39676
Slope walls	1 to 5 (Vertical to horizontal)	1 to 5 (Vertical to horizontal)	1 to 5 (Vertical to horizontal)
Percentage BOD_5 reduction in anaerobe ponds	40	70	70

AP= Anaerobic Pond; PFP= Primary Facultative Pond; SFP= Secondary Facultative Pond

(from mid-May to early August in 2010-11). The warm and cold months of the year were determined through the weather data of the previous years. Wastewater samples were taken monthly at the inlet and outlet of each pond. The collected samples were composite samples taken over a period of 48 hours. The samples were taken directly by means of 2 L beaker glass. Each sample of 2 L taken at a wastewater depth of 1 m was directly transferred to a 30 L sample container and fixed for physicochemical analysis (17). Sampling was conducted from December to June 2010.

Climate

Yazd has a relatively cold and dry climate. The maximum temperature may rise up to +38 °C in summer and fall down to -10 °C in winter. The average temperature in the coldest month is -7.48 °C. The average precipitation is around 300 mm, and the annual relative humidity is 50%.

Analyzed parameters

Total BOD_5, Chemical Oxygen Demand (COD) and SS were determined for both influent and effluent of the module. The measurement of flow was carried out by means of a Partial flume located at the inlet channel. Analytical approaches were based on the standard methods (20).

Results

Total performance evaluation system

The results obtained for each stage and for the total systems of M1 AWSP, are presented in Tables 2, 3 and 4 respectively.

The averages of raw wastewater flow rates entering the systems were 4,300 and 13,500 m^3/d for the AWSP system of M1, respectively, which were equivalent to the expected design. The measured average of BOD_5 and COD concentrations of raw wastewater, as around 272.08 and 577.13 mg/L, were also near the expected design concentrations of 250 and 550 mg/L, respectively, for BOD_5 and COD. However, the average SS concentration for raw wastewater, around 258.66 mg/L was upper than expected design concentration of 220 mg/L. Thus, the raw wastewater in Yazd could be classified as medium to strong, in terms of BOD_5, COD, and SS (14).

Analysis of pond performance parameters AWSP system M1

As Table 3 indicates, the removal efficiencies of BOD_5, COD, and SS for the APs with HRT=5 days and the PFPs

Table 2. The average removal efficiencies of parameters in the stabilization pond treatment

Parameter	Input (mg/l)	Output (mg/l)	Removal efficiency (%)
BOD_5	272.08	69.025	74.6
COD	577.13	136.75	76.31
TSS	258.6	136.5	47.2

BOD_5: Biochemical Oxygen Demand 5; COD: Chemical Oxygen Demand; TSS: Total Suspended Solids

Table 3. The average removal efficiency parameters of the anaerobic ponds

Parameter	Input to the anaerobic ponds (mg/l)	Anaerobic ponds output (mg/l)	Removal efficiency (%)
BOD_5	272.08	135.18	50.31
COD	577.13	307	46.24
TSS	258.66	139.75	45.97

BOD_5: Biochemical Oxygen Demand 5; COD: Chemical Oxygen Demand; TSS: Total Suspended Solids

Table 4. The mean change in TSS (mg/l) during summer and cold during the whole period of stabilization pond system

Sampling time		Raw wastewater input to anaerobic (mg/l)	The first optional input to wastewater pond (mg/l)	Effluent treatment plants (mg/l)
Three months of warm	June	352	174	215
	August	197	100.5	98
	July	240	104	133
	Average period of warm	263	126.16	148.6
Three months of cold	January	202	131	87
	February	301	189	155
	March	260	140	131
	Average period of cold	254.33	153.33	124.33
Average total study period		258.66	139.745	136.5

with HRT=11.3 days, were 50.31%, 46.24%, and 45.97%, respectively. The SFPs with the HRT=8 days had the removal efficiencies of 74.6%, 76.31%, and 47.2% for BOD_5, COD, and SS, respectively.

Based on meteorological studies, the average temperature of Yazd in the coldest and the hottest months are -0.3 °C and +33.6 °C, respectively. The average precipitation is around 300 mm and the annual relative humidity is 50 %. Table 5 summarizes the climatic conditions in Yazd, Iran (2010).

Discussion

M1 AWSP system

Wastewater stabilization pond system has been operated for municipal and industrial wastewater treatment worldwide. These systems are relatively affordable, especially in the tropics that construction and operation is simple and low cost. With respect to the effluent quality of the PFPs and SFPs and in comparison with the Iranian treated wastewater standards for agricultural irrigation that has indicated BOD_5, COD, and SS concentrations should be less than 100, 200, and 100 mg/L, respectively, the results indicated that the average effluent concentrations of BOD_5, COD, and SS were 135.18, 307, and 139.75 mg/L, respectively, for PFPs, and 69.025, 136.75, and 136.5 mg/L, respectively, for SFP. The effluent of the studied PFPs complied with the considered standards in terms of BOD_5 and COD concentrations. As shown in Figures 3, 4 and 5, although the average effluent concentrations of BOD_5 and COD of the PFPs were lower, the average concentration of effluent SS was higher than the concentration of the effluent SS of the SFPs. The main constraint in the WSPs is the high SS in the effluents, which is primarily due to high concentrations of algal cells in the effluent (21). Thus in practice, the SFPs would not be required and could be replaced with other PFPs, in parallel with the existing PFPs, to enhance the quantity of treated wastewater in forthcoming years and to optimize the treated wastewater quality.

Untreated wastewater can create many environmental problems. Low-tech wastewater treatment systems con-

Table 5. Climatic condition in Yazd, Iran

Parameters	Annual Mean
Temperature (°C)	19.9
Sun Light Hours (h/month)	274.9
Evaporation (mm/month)	255.2
Wind Speed (m/s)	9.5

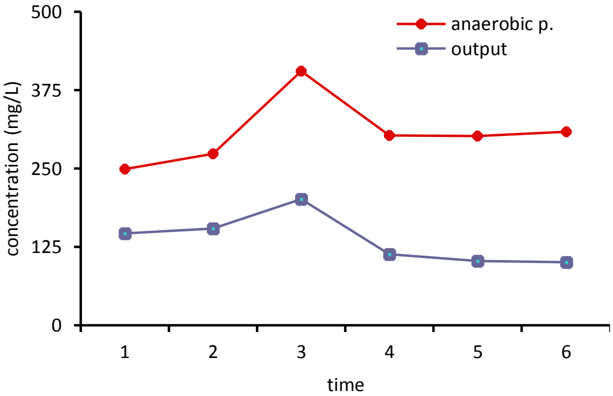

Figure 3. COD variations for M1 AWSP

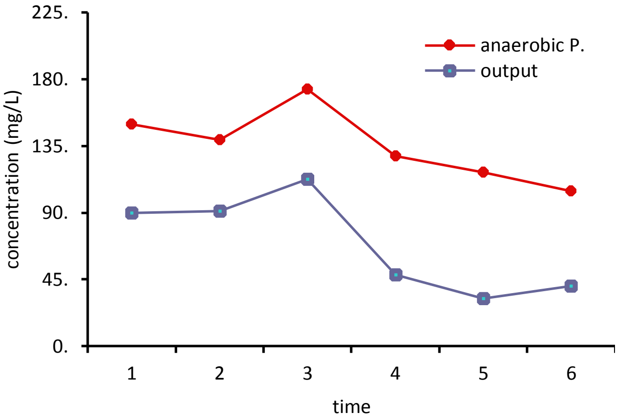

Figure 4. BOD_5 variations for M1 AWSP

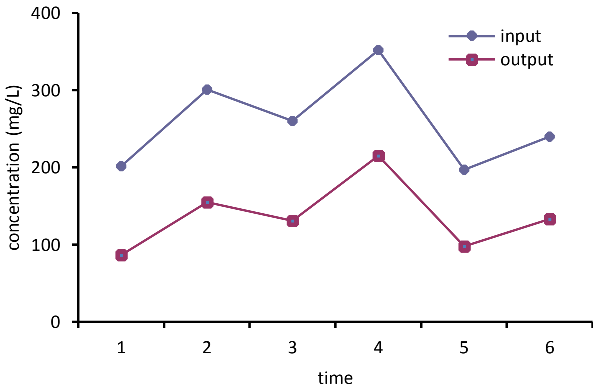

Figure 5. TSS variations for M1 AWSP

suming no energy or low-consuming systems improve our environment in addition to reduce economic costs. The range of BOD_5 concentrations of SPFs for M1 was less than the results obtained in a study conducted for stabilization ponds in Egypt (4). The removal efficiency of Yazd facility for BOD_5 was higher than the removal efficiency of another study that was conducted in Spain, as 54% (22). However, the removal efficiency of COD of that study was about the same as that in Yazd (about 70%). In a study that was carried out in Tanzania, the rate of COD removal was 66% for PFP, 68% for SFP1, 71% for Maturation Pond (MP), and the overall COD removal rate was about 94%, (23), much higher than that in Yazd which were 76.31% for M1. For conclusion, the TFP of M2 can be used as a serial SFP in order to increase Yazd wastewater plant capacity and effluent quality enhancing by population growth. In another way for enhancing effluent quality of Yazd facility, it could be practical to put some baffles in SPFs of both M1 to optimize HRT and plug flow condition of wastewater, and consequently, enhance removal efficiencies of BOD_5, COD and SS. The results show that the total amount of pollutants removed in this system is in good and acceptable situation compared to expensive mechanical systems with high energy consumption and operational problems. The share of the anaerobic pond removal was determined by stabilization pond system. Altogether, the removal of the BOD_5, COD parameters is significant in anaerobic ponds. High organic matter removal in the stabilization pond can be by a suitable retention time and high temperature because anaerobic pond performance significantly increases with increasing temperature, in a study was conducted by Pena on the anaerobic pond, removal of BOD_5, and COD was reported 59%, 68% respectively. In another study, the rate of BOD_5 removal at temperatures above 20 °C and retention time of more than 2.5 days, were reported 60%. They reported that the main mechanism in the anaerobic pond is the removal of SSs through the settling. Anaerobic pond is the first pond and its share is up in the removal. Therefore, the above removal of the anaerobic ponds substantially reduces the concentration into facultative ponds. Naddafi *et al* (24) reported that anaerobic pond of the first module of Arak stabilization pond has efficiency of 40% and 47% for BOD_5 and COD, respectively, higher than that of AP in YWSPs. Employment of skilled operators is expensive, and energy consumption due to its related problems from environmental and economical point of view is important worldwide in recent years, and Iran does not have a suitable state in energy consumption, therefore, YWSPs upgrading programs should be considered based on fundamentals with no need for energy resources and no expert operators. As mentioned above, the problems of YWSPs are related to operational and design parameters, and the quality of effluent from this wastewater treatment plant may be improved by controlling entered wastewater and supply of distributed flows in ponds. Determination of hydraulic regime and its relationship with pond geometry is another important issue which should be considered in YWSPs. Also, training personnel to monitor and evaluate the pond performance and response to upgrading effluent quality is important and should be recognized.

Conclusion
Based on this research, it can be concluded that the stabilization pond system is one of the appropriate techniques used for the treatment of various types of wastewater worldwide. These systems can be constructed with local materials and operated without the need for skilled workers. The results showed that the variation of organic load, pH, Electrical Conductivity (EC) and season variation had no effects on organic matter removal, and the removal of BOD_5 was approximately constant.

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Ethical issues
We certify that all data collected during the study is presented in this manuscript and no data from the study has been or will be published separately.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
MF, MK, MHE and EAM conceived and designed the study. EAM and MTG performed the literature search and wrote the manuscript. All authors participated in the data acquisition, analysis and interpretation. All authors critically reviewed, refined and approved the manuscript.

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