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Performance of an overland flow system for advanced treatment of wastewater plant effluent

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Abstract

Overland flow (OF) systems were evaluated and compared for advanced treatment of municipal and industrial effluents, including nutrients and nondegradable chemical oxygen demand (COD) removal. Three pilot plants were constructed at the Shahin Shahr Wastewater Treatment Plant (WWTP), Isfahan, Iran. Each pilot was assigned a specific wastewater and all were simultaneously operated for 8 months. Treatment of primary effluent, activated sludge secondary effluent, and lagoon effluent of textile wastewater was investigated at application rates (ARs) of 0.15, 0.25, and $0.35\,m^3\,m^{-1}\,h^{-1}$. During 5 months of stable operation after a 3-month acclimation period, mean removals of total 5-day biochemical oxygen demand ($TBOD_5$), total COD (TCOD), total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP) and turbidity were 74.5%, 54.8%, 66.2%, 39.4%, 35.8%, and 67.7% for primary effluent; 52.9%, 52.9%, 66.5%, 44.4%, 39.8%, and 50.1% for activated sludge effluent; 65.7%, 58.7%, 70.3%, 41.7%, 41.3%, and 54.9% for textile wastewater lagoon effluent, respectively. The model of Smith and Schroeder, 1985. Field studies of the overland flow process for the treatment of raw and primary treated municipal wastewater. Journal of Water Pollution Control Federation 57, 785–794] was satisfactory for $TBOD_5$. For all treatment parameters a standard first-order removal model was inadequate to represent the data but a modified first-order model provided a satisfactory fit to the data. Based on the results of this study, it can be concluded that an OF system as advanced treatment had the ability to meet effluent discharge permit limits and was an economical replacement for stabilization ponds and mechanical treatment options.

Keywords: Advanced treatment; Overland flow; Primary effluent; Activated sludge; Textile wastewater

1. Introduction

Water resources quality control is a vital task for all countries. Wastewaters and plant effluents can seriously deteriorate the quality of their receiving waters. Advanced treatments are often required to produce an acceptable effluent that will not compromise water resources quality and these effluents in turn can increase the potential of water reuse.

Currently, effluent quality of most biological secondary treatment plants in developing countries does not meet the specified level of permit discharge defined by their regulations. Effluent requirements for Iran are listed in Table 1; these standards are near those in the US (Federal Register, 1988, 1989) and elsewhere in the world.

Operational problems mostly due to the lack of skilled operators and in some cases poor design are causes of treatment plant failures. At the moment in these countries, using advanced physical and chemical treatments to improve plant effluents is usually not feasible because of capital and operational costs and also lack of specialized operators. Land is also relatively inexpensive. Therefore, natural treatment processes are appropriate alternatives. Natural treatment systems include wetlands, aquatic, and land treatment systems. Compared to advanced

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Table 1
Wastewater effluent quality standards in Iran[a]

Effluent use	BOD_5 ($mg\,L^{-1}$)	COD ($mg\,L^{-1}$)	TSS ($mg\,L^{-1}$)
Discharged to surface water	30	50	30
Irrigation	60	100	60

[a]DOE (2001).

physical–chemical or biological treatment systems these systems have less capital expenditures and lower operational costs; also they are easier to operate.

Overland flow (OF) systems, as a natural treatment alternative with advantages such as low construction and operation costs, easy operation, low detention time, and low-energy requirements, have an inherent potential for advanced treatment of industrial and municipal effluents. In OF systems, the vegetative cover growing on a relatively impermeable sloped ground prevents flow channeling and soil erosion. When the applied influent discharges on the top of the bed, it slowly flows on the sloped vegetative bed and is treated by different physical, chemical, and biological processes (Crites and Tchobanoglous, 1998; Droste, 1997; Reed et al., 1995; USEPA, 1981, 1984; WPCF, 1990). The OF system effluent is then collected at the bottom of the bed.

Experience with several experimental OF systems has led to improved design procedures. Scott and Fulton (1979) have related treatment performance of an OF system to slope length (or length of the OF plot). Martel et al. (1980, 1982) and Jenkins et al. (1985) have used an approach that relates pollution removal of an OF system to detention time on the slope. In another approach, Smith (1982), Smith and Schroeder (1985), and Witherow and Bledsoe (1986) have related removal efficiency of an OF system to application rate (AR) and slope length.

The performance of OF systems has also been studied by numerous investigators (Abernathy et al., 1985; Overman and Wolfe, 1989; Surampalli et al., 1996; Turner et al., 1994; Tyrrel et al., 2002; Wightman et al., 1983; Zirschky et al., 1989). Performance data obtained from these studies indicate the system can achieve greater than 90% reduction of BOD_5 and total suspended solids (TSS), and 70–90% reduction of nitrogen. Because performance of an OF system, as other natural treatment systems, depends on the soil, wastewater, vegetative cover, and climate characteristics, for each specific condition additional data from full-size or pilot plant operating OF systems are needed to verify the design models in the literature.

An OF system treating raw wastewater in Easley, SC (Abernathy et al., 1985) had removal efficiencies of BOD, TSS, and TKN between 70% and 90% and for total phosphorus (TP) between 40% and 60%. In Florida, Overman and Wolfe (1989) found that an OF system receiving secondary effluent removed approximately 90% of BOD_5 and TSS. Surampalli et al. (1996) conducted a study to evaluate the performance of an OF system under winter and summer conditions. The average removal efficiencies for BOD_5 and SS were 89% and 85%, respectively, in warm weather; and 81% and 69%, respectively, for cold weather. Turner et al. (1994) in Garland, TX, examined phosphorous removal from secondary effluent using OF and found the highest level of 77% during the summer and 52% during the winter season. In Hyrum, UT, Wightman et al. (1983) evaluated the performance of an OF system and found reductions of 87–93% for BOD_5 and 91–95% for TSS. In Garland, TX, Zirschky et al. (1989) observed that the OF process removed up to 97% of ammonia from secondary effluent. Tyrrel et al. (2002) found that ammonia removal from leachate applied to experimental OF systems was slow compared to conventional wastewater treatment.

Besides a performance evaluation of systems in Isfahan, Iran, the objectives of this study included a side-by-side comparison of OF treatment for waters of municipal and industrial origin, specifically a textile wastewater. Furthermore, the possibility of replacing secondary biological treatment with OF treatment was explored. Results were examined using different models.

2. Materials and methods

Three experimental pilot systems (Fig. 1), each with dimensions of 4.5 m × 40 m and a down-slope of 4%, were constructed at the Shahin Shahr Wastewater Treatment Plant (WWTP) in Isfahan, Iran. The OF pilot areas were separated by barriers of soil mounded to a height of approximately 0.3 m and width of 0.5 m.

The Shahin Shahr WWTP is a secondary WWTP with an activated sludge process for biological treatment. Wastewater from a textile mill is given preliminary treatment in a lagoon system consisting of anaerobic (depth 4.5 m), facultative (depth 3.0 m), and maturation (depth 1.5 m) ponds in series and then discharged to the Shahin Shahr WWTP. Influent and effluent characteristics of textile wastewater for the lagoon system are given in Table 2. The hydraulic retention time ranges between 40 and 60 days in the entire lagoon system. Although nutrient concentrations in the effluent of textile WWTP are low compared to the primary and secondary effluent studied in this research (Table 3), organics concentrations are high.

Before any vegetation was planted, the soil of the pilots was mechanically graded and mechanically compacted to increase its impermeability. The soil in the system consisted of 26% clay, 68.3% silt, and 5.7% sand which is classified as a silty loam soil. The measured soil permeabilities before and after compaction were 0.65 and 0.18 $cm\,h^{-1}$, respectively. Permeability values less than 0.5 $cm\,h^{-1}$ are recommended by the US Environmental Protection Agency design manual for OF systems (USEPA, 1984).

A 15 cm layer of loose soil was spread over the compacted soil to promote the growth and health of the grass cover. For vegetation, a mixture of five grasses