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Reuse of lagoon effluents in agriculture by post-treatment in a step feed dual treatment process

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Abstract

The main constraint in lagoon treatment is the high suspended solids (SS) in the effluents, which is primarily due to high concentrations of algal cells in the finished effluent. The objective of this study was to remove turbidity originating from algae present in oxidation pond effluents by an easy and inexpensive method. For this reason, a novel lab-scale step feed dual treatment (SFDT) process was developed and the effectiveness of the trickling filter (TF) unit within the system in removing algae and organic matter was investigated. The SFDT process developed in this study is a unique and inexpensive way to scavenge algae from oxidation pond effluents. As opposed to earlier and somewhat unsuccessful studies where pond effluent post treatment was tested on once-through trickling filters, in this study pond effluents were directed to a step fed TF, so as to provide a dual treatment. Step feeding provided the necessary substrate to maintain a biofilm in TF, thereby affecting organic particles interception. The stabilization pond was not simulated in the study since the main focus was on the behaviour of the TF unit. The hydraulic loading rate (HLR) (0.5–2–4 m^3/m^2 day), influent COD (150–550 mg/L) and influent Chl-a concentrations (250–600 μg/L) were selected as operational variables. It was observed that, in general, removal percentages for turbidity, Chl-a, SS and COD increased considerably with the decreasing HLR, such as the removal efficiency of Chl-a was increased from 89.4% to about 97% when HLR was decreased from 4 m^3/m^2 day to 2 m^3/m^2 day. As a result, trickling filter produced clear effluents, with less than 2 NTU and the removal efficiency of turbidity being higher than 88%, and also removal percentages for Chl-a were higher than 95% for most of the cases.

Keywords: Algae removal; Stabilization ponds; Trickling filter; Wastewater reuse

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1. Introduction

Waste stabilization ponds are commonly used as efficient means of wastewater treatment relying on little technology and minimal, albeit regular, maintenance. Their low capital and operating costs and capability to handle fluctuating organic and hydraulic loads have been valued for years in rural regions and in many countries wherever suitable land is available at reasonable cost. The major limitation of this type of treatment is the high effluent suspended solids (SS) concentrations mainly due to high concentrations of algal cells in the finished effluent. The presence of such algae can impose serious constraints on effluent reuse potential, which is particularly important in water-scarce regions. According to WHO and other guide lines, reuse waters should bear less than 1 parasitic eggs or protozoa per liter and/or contain less than 2 NTU [1]. Moreover, current re-use standards call for almost SS-free waters for agricultural reuse.

Since pond effluents contain considerable amounts of algae, they are generally unable to satisfy stringent water-quality standards required for disposal or reuse for irrigation [2]. As a yardstick of the effect that algae in suspension have on the chemical oxygen demand (COD) of a pond effluent the following factors could be used as rough approximation: according to Meiring and Oellerman, [3] 100 μg/L of chlorophyll-a (Chl-a) give rise to 5.6 mg COD/L. Similarly, Shipin et al. [4] reports this figure as 10 mg/L COD (3 mg/L biochemical oxygen demand (BOD)) and 20 mg/L suspended solids (SS). The concentration of algae in a healthy facultative pond depends on the loading and temperature, but is usually in the range 500–2000 μg chlorophyll-a per liter [5], representing an effluent COD and SS concentration of 28–200 mg/L and 100–400 mg/L respectively. It is obvious that algae need to be removed from effluents prior to discharge or reuse.

Algae may be removed by several methods, each of which is doubtful in economics or operation from practical point of view. Processes, such as centrifugation [6,7], micro-straining [6–10], coagulation–flocculation [6,7,11–15], sand filters [2,16–18], rock filters [10,19–24] to scavenge algae from lagoon effluents have been discussed extensively in the literature. Every method of algae removal from ponds has specific advantages and disadvantages, but the methods selected must be specific to the particular treatment situation.

The rock filters, which are assumed an alternative for the removal of algae from lagoon effluents, consists of submerged bed of rocks through which lagoon effluent pass horizontally; this allows the algae to settle out on the rock surface as the liquid flows through the void spaces [10,20]. Sedimentation was found to be the primary mechanism by which algae, particularly green algae and flagellates, were removed within the rock filter [20]. The principal advantages of the rock filters were set as their relatively low construction costs and simple operation. However, rock filters have lower removal efficiencies [22,23] and odor problems can occur, and the design life for filters and the cleaning procedures have not been firmly established. High ammonia nitrogen concentrations in rock filter effluents could also limit application of the process. Another drawback of rock filters is the production of hydrogen sulfide during summer and early fall when the filters become anaerobic. Effluent aeration would be required before discharge in many cases. The rate of sludge accumulation in the voids of the rock remains unknown [10].

An additional, promising alternative for the removal of algae from waste stabilization pond effluents could be the trickling filter (TF), which couples biological and mechanical filtration to effectively reduce BOD and TSS in the effluents. TFs are capable of achieving BOD and TSS removal efficiencies greater than 80%, producing an effluent suitable for reclamation (landscape irrigation and soil conditioning). At an incremental cost, addition of other treatment components (e.g. wetlands, ponds and sand filters) boosts overall removal rates of BOD and TSS to more than 90%, creating a water source acceptable for human contact [25].

Shipin et al. [26] developed a PETRO (Pond Enhanced Treatment and Operation) process and it features an anaerobic pond (with a fermentation pit) followed by an oxidation pond which is next followed by a trickling filter and a clarifier to remove algae and reduce effluent BOD and TSS. The key element in this configuration was the embedded algae removing trickling filter. The operation of the system depended on the establishment of a heterotrophic biofilm growing on the filter medium with the partially treated effluents. The system produced a clear effluent. However the system is too complex involving anaerobic ponds, nitrifying towers, post pond-treatment and extensive effluents recirculation and hence requiring intensive management effort. The complexity of the process takes away the fundamental merits of pond systems, which are easy with simplicity of operation, low cost and having minimum level of management efforts. The selected SFDT process therefore aims to simplify pond effluent polishing process while minimizing both running and capital costs. It should be noted that cost of wastewater treatment in irrigational reuse is vitally important as revenue gained at the harvest of crops is marginally, if at all, greater than the treatment cost in other systems.

Potential use of TF as a system to remove algae from the pond effluents seemed worth studying. Currently there are numerous lagoons in Turkey awaiting upgrade. Therefore, the objective of the present study was set as to analyze effectiveness of a TF unit operated within the proposed SFDT system in removing turbidity and organic matter. To this purpose, an experimental set up was designed as to simulate a system with both TF and oxidation pond. This system was named as step feed dual treatment (SFDT). The SFDT process introduced here is a unique and inexpensive system to scavenge algae from oxidation pond effluents. In this system, raw wastewater (influent) is firstly treated in an oxidation pond, then effluent is directed for post treatment in a TF, hence dual treatment is achieved. Moreover, by step feeding, a portion of raw wastewater to maintain the biofilm on TF, together with oxidation pond effluent containing algae, is directed to the TF in SFDT arrangement (Fig. 1b).

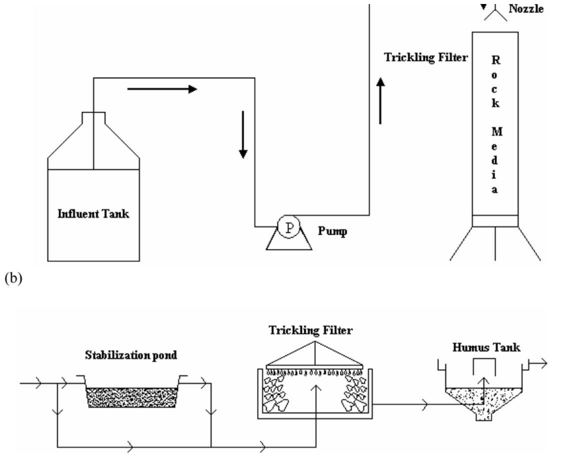

Fig. 1. Schematic representation of experimental set-up of step feed dual treatment (SFDT) (a) and its application in the field (b).

2. Materials and methods

2.1. Experimental set-up

The experimental set-up used to simulate SFDT process in the laboratory is shown in Fig. 1a. Stabilization pond was not simulated in the experimental set-up as the main objective of the study is to observe TF ability to scavenge algae from pond effluent. For this purpose, an influent tank containing synthetic wastewater and algae was used to feed TF within this system (Fig. 1a). Composition of the synthetic wastewater (Table 1) was arranged to simulate mixture of raw wastewater and oxidation pond effluents rich with algae entering the TF unit. The experimental set-up was consisting of an algae tank, an influent tank, a pump and a trickling filter column. The model trickling filter was dosed by a pump from the influent tank with synthetic wastewater containing different concentrations of algae. In an actual system this could be established by sending a portion of the raw wastewater directly to TF while rest going through a lagoon then TF, as shown in Fig. 1b.

2.2. Trickling filter

A simple lab-scale trickling (Fig. 1a) filter was constructed from a PVC pipe of 65 cm height and an inner diameter of 10 cm. Filter medium consisted of previously cleaned rocks (1.27–1.91 cm). The rock medium was supported by a perforated plexiglass plate at the bottom of which rested on a steel tripod giving extra support. Filter was fed through an influent hose. The influent was pumped to the top of the filter, and with the aid of a nozzle, sprayed uniformly over the filter.

2.3. Growth medium

Synthetic wastewater that was employed to maintain a biofilm over the filter media which was expected to scavenge microalgae from the effluents, was composed of protesose-peptone: 517 or 141 mg/L, NaCl: 407.4 mg/L, Na_2SO_4: 44.6 mg/L, K_2HPO_4: 44.6 mg/L, $MgCI_2.6H_20$: 3.7 mg/L, $FeCI_2.2H_20$: 3.7 mg/L, $CaCI_2.2H_20$: 3.7 mg/L, $MnSO_4$: 0.057 mg/L, H_2MoO_4: 0.031 mg/L, NaOH: 0.008 mg/L, $ZnSO_4$: 0.046 mg/L, $CoSO_4$: 0.049 mg/L, $CuSO_4$: 0.076 mg/L [27]. Proteose-peptone served as source for organic carbon and organic nitrogen in the simulated wastewater, and was added to the medium to maintain the intended COD, 517 mg/L for 550 mg/L COD or 141 mg/L for 150 mg/L COD. Phosphate salts were introduced to the medium to provide both buffer action and as source of phosphorous to microorganisms.

2.4. Algal growth system

Algae collected from Çubuk 1 dam, located near Ankara-Turkey, were inoculated into an algae tank. The Modified Bold's Basal Medium (BBM) [28] was used as inorganic nutrient medium to supplement algal growth. Algae tank was aerated by an air pump to provide gentle mixing and CO_2. Lighting was provided for 12 h/day by using an 18 W fluorescent lamp and temperature in the tank was maintained at about 25°C.

2.5. Experiments

The trickling filter unit of SFDT was operated continuously without interruption for 13 months. Filtration runs were made with different influent characteristics and hydraulic parameters. Table 1 shows the combinations applied during these runs. As seen from this table, a set of 12 experiments were designed. The selected independent variable parameters were HLR (m^3/m^2 day), COD_{inf} (mg/L) and Chl-a_{inf} concentration (μg/L).

For each experimental run an appropriate amount of algae mixture was drawn from the algae tank and mixed with synthetic wastewater to make up the desired influent combination. The amounts of algae and peptone to be added into the feed tank was adjusted according to the desired COD (i.e. COD_{inf}) and Chl-a (i.e. Chl-a_{inf}) levels in the influent. The Chl-a concentrations reportedly correlates well with viable algae counts according to Swanson and Williamson [20]. The minimum COD concentration in Table 1 was selected somewhat arbitrarily in order to maintain a healthy biofilm on the media surface at all times, since Shipin et al. [26] have proven that filter performance relies on this.

Filter effluents were continuously analyzed for turbidity and COD to observe that steady state conditions are reached. Steady state conditions were usually reached within 2–3 weeks. At steady-state conditions TF effluents were left to settle for 2 h in a jar to mimic the humus tank. Effluent turbidity expressed in nephelometric turbidity units (NTU), COD, and Chl-a measurements were carried out in the supernatant, in duplicates and the average of the measurements were taken.

Table 1
Average influent and effluent Chl-a concentrations (μg Chl-a/L)[a], turbidity values (NTU), TSS concentrations (mg/L)[a] and COD values (mg/L)[a] observed

Influent					HLR = 0.5 m^3/m^2 day				HLR = 2 m^3/m^2 day				HLR = 4 m^3/m^2 day			
SET[b]	Chl-a	Turbidity[c]	COD	TSS	Effluent				Effluent				Effluent			
					Chl-a	Turbidity	TSS	COD	Chl-a	Turbidity	TSS	COD	Chl-a	Turbidity	TSS	COD
A	250	[20–24] 22	150	64.8 ± 3.5	0.5 ± 0.2	1.0	1.8 ± 0.6	25.2 ± 1.4	7.0 ± 1.4	1.3	2.5 ± 0.8	48.8 ± 0.3	27.4 ± 1.4	2.5	3.6 ± 0.7	49.8 ± 2.3
B	600	[28–35] 32	150	97.9 ± 1.6	13.1 ± 0.8	1.4	3.4 ± 0.1	47.0 ± 3.4	26.9 ± 1.7	4.4	11.1 ± 0.6	56.6 ± 4	250.7 ± 0.4	11.6	26.6 ± 2.4	56.0 ± 2.8
C	250	[20–47] 28	550	65.7 ± 2.3	0.3 ± 0.1	1.0	1.5 ± 0.1	44.4 ± 2.3	11.1 ± 1.5	2.4	2.8 ± 0.6	92.1 ± 3.5	45.8 ± 1.1	12.4	22.2 ± 1.7	129.8 ± 2.3
D	600	[27–83] 49	550	98.9 ± 3.6	2.4 ± 0	1.2	2.5 ± 1	33.8 ± 2.5	68.1 ± 7	6.7	15.2 ± 0.7	121.0 ± 0.3	184.0 ± 7.5	23.8	36.2 ± 1.4	136.8 ± 2.0

[a] Mean ± Standard Deviation.
[b] Set A, B, C and D represents the operational conditions indicated in Fig. 1 (a–d).
[c] [Range] mean.
HLR, Hydraulic loading rate.

2.6. Analytical techniques

The SS and Chl-a measurements were carried out according to the Standard Methods [29]. Turbidity was expressed in nephelometric turbidity units (NTU) [29]. The COD of the samples were measured by an EPA approved HACH analysis kit, using a digester block and using HACH DR2000 colorimeter.

3. Results and discussion

A factorial design, as summarized in Table 1, was randomly executed under the conditions presented in the methods section. The results obtained are presented in Fig. 2 (a–d). According to these results it is clear that, in general, trickling filter performed very well in terms of Chl-a, COD, turbidity and SS removals; most being higher than 85% for the cases of HLR between 0.5 and 2 m^3/m^2 day. Poor performance figures (55 and 68% removals) were observed when HLR was increased to its highest value, 4 m^3/m^2 day; when Chl-a$_{inf}$ was also the highest, i.e. 600 µg/L.

Whereas highest Chl-a removals, around 99%, were obtained when HLR was 0.5 m^3/m^2 day, irrespective of COD$_{inf}$ or Chl-a$_{inf}$. It is obvious from Fig. 2a that, apart from HRT, the influent Chl-a concentration inversely affects Chl-a removal. The effluent Chl-a concentrations obtained are presented in Table 1.

In a thesis study using rock filter, Oran [22] also found inverse relationship between removal efficiency and HLR. However, in her study, up to 38% Chl-a removal was obtained at HLR of 2 m^3/m^2 day, and removal did not exceed 64.8% at 0.5 m^3/m^2 day HLR. Whereas in this study 89.4% removal became possible at HLR of 4 m^3/m^2 day, when influent Chl-a concentration was 250 µg/L, comparable to that employed in Oran's study [22]. The major difference between the two studies is thought to be in the inherent algal removal processes. In the rock filter it is believed that death and settling of algae in the

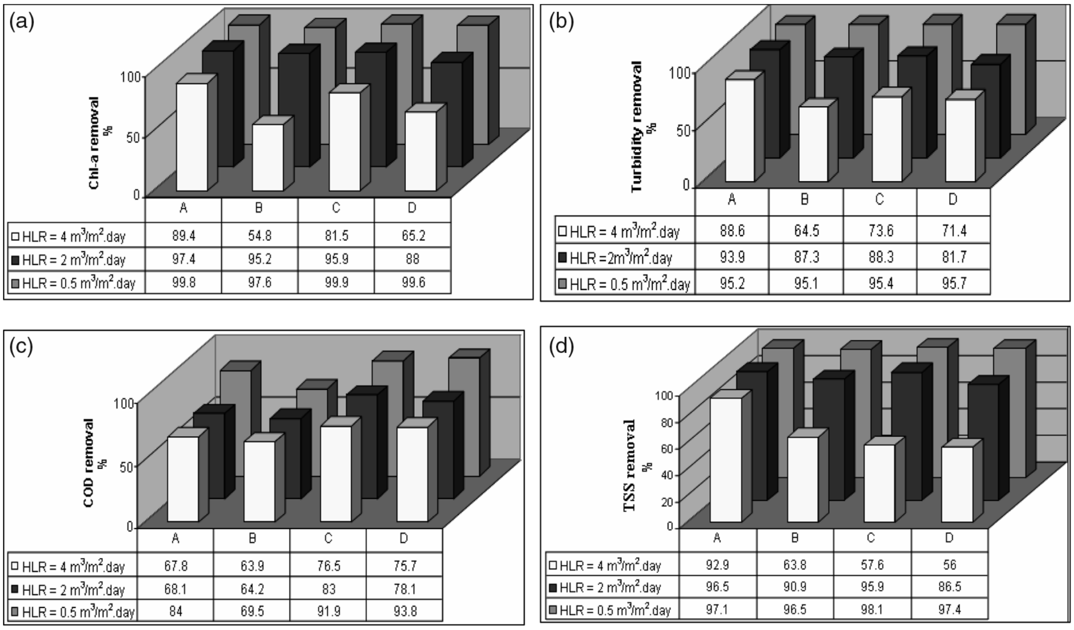

Fig. 2. Removal efficiency of TF in SFDT (a) Chl-a removal (b)Turbidity removal (c) COD removal (d) SS removal in TF of SFDT.

dark voids of the rock medium plays the major role in algae removal; whereas in SFDT, interception of organic particulates by the growing biofilm, just as flocks in activated sludge do by adsorbing colloidal particles, play the major role in algae removal.

Turbidity removal efficiencies attained are illustrated in Fig. 2b. The inverse effect of HLR on the turbidity removal efficiency can be clearly seen from this figure. The highest removals, around 95%, were also obtained when HLR was 0.5 m^3/m^2 day.

Effluent turbidity values are presented in Table 1. The system produced clear effluents with turbidity values less than 2 NTU for all the cases HLR of 0.5 m^3/m^2 day. Effluent NTU readings are important in that WHO agricultural reuse guideline calls for less or equal to 2 NTU in the effluents to be used for unrestricted irrigation [1].

The COD removals obtained in the study are presented in Fig. 2c. As can be seen from this figure, COD removals were again higher at lower HLR values. Whereas, the influent COD concentration had an increasing effect on COD removal. Accordingly, at higher influent COD concentration higher removals were obtained. Effluent COD concentrations observed in these experiments are tabulated in Table 1.

Another quality parameter studied in these studies was the total suspended solids. The TSS removals obtained are shown in Fig. 2d. As can be seen from this figure, highest removals were obtained at 0.5 and 2 m^3/m^2 day HLR. As with the other parameters lowest TSS removals were obtained at the highest, 4 m^3/m^2 day, HLR value.

Effluent TSS concentrations observed in this study are given in Table 1. As it can be seen from this table and also from Fig. 2, HLR had an important effect on TSS removal efficiency especially when Chl-a_{inf} values were higher (i.e. cases B and D). HLR was found inversely related with the TSS removal. Considering that suspended solids in the influent were mainly algal in origin, one should expect similar observations with the Chl-a removals. As a matter of fact, findings for the removal of Chl-a and TSS were very similar.

As can be seen from Table 1, system produced a clear effluent for most of the cases. Some pinpoint flocs were usually present in the simulated humus tank but the amount of sludge produced was very little, stable and rapidly settling.

4. Conclusions

In this study, the removal of Chl-a, SS and turbidity in a lab-scale TF unit of a SFDT process was investigated. The SFDT process developed in this study is a unique and inexpensive way to scavenge algae from pond effluents. Following are the conclusions drawn from this study:

The SFDT process produced clear effluents with <2 NTU, for most of the experimental sets tested. WHO agricultural reuse standard calls for less than (or equal to) 2 NTU in the effluents which are to be used for unrestricted irrigation.

Most important parameter affecting the performance of TF in SFDT was found to be HLR. Highest removals were obtained at the low HLRs. Data obtained from the experiments showed that when HLR (m^3/m^2 day) was increased from 0.5 to 2, a slight decrease was observed in Chl-a, NTU and COD removals; though more than 90% removal of each was attained in every case, except for the COD. The lowest removal efficiencies were observed for all the quality parameters when hydraulic loading rate was 4 m^3/m^2 day.

The SFDT system should require minimum of maintenance, and not more than oxidation ponds and trickling filters together. Both processes are known to be the least maintenance requiring amongst the alternative waste treatment processes.

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