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## Technical Note

# Municipal wastewater treatment using novel constructed soil filter system

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## Abstract

The study gives a new approach for contaminant removal from municipal wastewater using constructed soil filter (CSF) and presents performance of two CSF units located in Mumbai, India. In this system, natural weathered rock is formulated which combines sedimentation, infiltration and biochemical processes to remove suspended solids and oxidisable organics and inorganics of the wastewater. Results show elevated dissolved oxygen (DO) levels, removal of COD (136–205 to 38–40 mg l<sup>-1</sup>) and BOD (80–125 to less than 12 mg l<sup>-1</sup>) suspended solids from 135–203 to 13–18 mg l<sup>-1</sup> and turbidity from 84–124 to 8–11 NTU, bacterial removal of 2.4–3.1 log order for Total coliform and Fecal coliform from site I which is almost 8 years old facility, and site II which is 3 years old. Estimated hydraulic retention time of 0.5–1.0 h, hydraulic loading of 0.036–0.047 m<sup>3</sup> m<sup>-2</sup> h<sup>-1</sup>, no pretreatment, high DO levels in the effluent, no bio-sludge production, no mechanical aeration, low energy requirement (0.04 kW h m<sup>-3</sup>) and green aesthetic ambience are its unique features.

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**Keywords:** Constructed soil filter (CSF); Soil biotechnology; SBT; Wastewater purification; Pathogen removal

## 1. Introduction

Water resources on earth are diminishing rapidly and human activities continue to affect detrimentally the quality and quantity of existing fresh water resources. Perks et al. (2004) has projected a water demand of 18000 million litres per day (MLD) and wastewater generation of 14400 MLD for the Mumbai city by 2025. So there is urgent need for fresh water conservation and wastewater renovation (Kivaisi, 2001).

There are conventional and non conventional approaches for wastewater treatment. For waters already treated to primary and secondary levels, land treatment is a promising tertiary treatment technology. There are many types of land treatment system namely slow-rate irrigation system (Ou et al., 1997), overland flow system (Smith and

Schroeder, 1985), rapid infiltration systems (Bouwer, 1985), sand filters (Bahgat et al., 1999), soil infiltration systems (Jenssen and Siegrist, 1990) and intermittent buried sand filters (Schudel and Boller, 1990). Operation cost, mismatch of operating requirements with local skills and space constraint has limited their applications (Bahgat et al., 1999).

## 2. Constructed soil filter (CSF) system

CSF is a new process wherein formulated media comprising local weathered rock of suitable mineral constitution and culture containing native microflora and bio-indicator plants is used to bring about treatment. In CSF system, geophagus worm – *Pheretima elongata* (*k* selected organism) is cultured to maintain required soil microbial ecology. US patent covers details (Shankar et al., 2005). Experimental studies with lab scale CSF show oxygen transfer coefficient in the range of 10<sup>-2</sup>–10<sup>-3</sup> s<sup>-1</sup> (Kadam, 2007) and reduction potentials of more than

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600 mV for organic loading of less than  $0.15 \text{ kg m}^{-2} \text{ d}^{-1}$  for hydraulic loading of  $0.35 \text{ m}^3 \text{ m}^{-2} \text{ d}^{-1}$  (Pattanaik, 2000).

In this work we present results for wastewater purification in two CSF facilities monitored over a period of 9–10 months. We show that CSF with natural oxygen supply and microbial ecology in place brings about primary, secondary and tertiary level wastewater purification in one pass.

### 3. Study site

#### 3.1. Plant description

The facilities are located in Mumbai, India. Mumbai being a port city shows very little variation in temperature ranging from 24 to 32 °C with heavy rainfall of 2500 mm during June–October. Both the plants receive raw sewage from municipality mixed with septic tank effluent and the treated water is used for irrigation of golf complex.

These systems are housed in reinforced cement concrete (site I), stone-masonry or soil embankment (site II) and consist of an impervious containment typically below ground, 0.7 m deep. At the bottom, a 0.3 m of underdrain layer of stone or rubble, above which there is a 0.4 m layer of media housing culture and bioindicator plants. Soil medium used here is completely weathered Deccan Trap Basalt soil found in and around Mumbai. The design has suitable provision for manual removal of suspended solids from the biofilter surface. Fig. 1 shows layout of the media. Distribution of wastewater over the media is achieved via pumping, piping and distribution arrangements.

#### 3.2. Process description and operation

The process can be operated on batch or continuous mode. However, at these sites the system operates in a batch mode in which wastewater is pumped and applied onto the top surface of the system as shown in Fig. 1. Typical hydraulic loading is in the range of  $0.036\text{--}0.047 \text{ m}^3 \text{ m}^{-2} \text{ h}^{-1}$ . A batch volume of  $30 \text{ m}^3$  or  $300 \text{ m}^3$  is pumped into the trenches of the respective sites. Water first percolates through the trenches and gets collected into the collection tank. It is then distributed over the media through distribution system in order to achieve high solid

Table 1  
Constructed soil filter plant details of the two sites

Site	I	II
Wastewater	Domestic + septic tank	Domestic + septic tank
Batch volume ( $\text{m}^3 \text{ d}^{-1}$ )	30	300
Design capacity ( $\text{m}^3 \text{ d}^{-1}$ )	120	1000
Pretreatment	No	No
<i>BED</i>		
Bed dimensions (m)	$20 \times 12 \times 0.7$	$50 \times 30 \times 0.7$
Bed surface area ( $\text{m}^2$ )	240	1500
Upper media ( $\text{m}^3$ )	72	317
Lower media ( $\text{m}^3$ )	96	450
<i>Hydraulics</i>		
Flow	Vertical	Vertical
Mean hydraulic load ( $\text{m h}^{-1}$ )	0.027	0.018
Raw flow ( $\text{m}^3 \text{ h}^{-1}$ )	14.4	39.6
Recycle flow ( $\text{m}^3 \text{ h}^{-1}$ )	10.8	54.0
Batch time: h	4.67 (2.40 + 2.0)	11 (5.30 + 5.30)
Plant age	1995 onwards	2003 onwards

I: site located at Bombay Presidency Golf club, Chembur, Mumbai, India;  
II: site located at Bombay Presidency Golf club, Chembur, Mumbai, India.

liquid contact. The treated water is collected in the collection tank. Recirculation is done if necessary. Details of the sites and the operating conditions are given in Table 1.

### 4. Materials and methods

#### 4.1. Physicochemical and microbial analysis

Samples of raw water and treated water were collected from the respective sites once in a week and analyzed during the period from October 2003 to July 2004. Samples were collected in sterile 2 l plastic cans, brought to the laboratory and stored at 4 °C before analysis. Water samples were filtered through Millipore membrane filters ( $0.45 \mu\text{m}$ ) for all physicochemical analysis except for solids.

Water temperature, conductivity and total dissolved solids (TDS) were measured immediately using WTW (Germany) Inolab1 conductivity meter; pH and dissolved oxygen (DO) using WTW (Germany) Inolab1 pH/Oxi meter; turbidity using WTW (Germany) Turb 550. Chemical analysis viz. BOD (5-d BOD test), COD (close reflux),

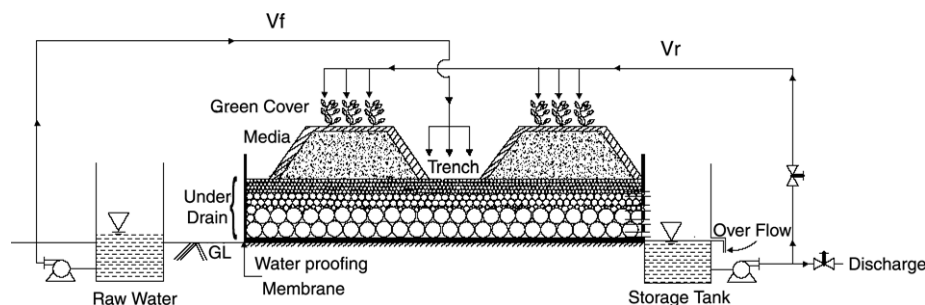


Fig. 1. Upper and Lower media showing layout for processing water.

total suspended solids (TSS), volatile suspended solids (VSS), Orthophosphate-P (stannous chloride method), Total Kjeldahl Nitrogen (TKN; ammonia distillation method) and Nitrite-N (coupling diazotation followed with colorimetric analysis) were performed following Standard Methods (APHA, 1998).  $\text{NO}_3^-$  and  $\text{NH}_4^+$  was measured with WTW combination electrode (Model no.  $\text{NO}_3^-$  106674) and ELIT double junction electrode (ELIT 8051  $\text{NH}_4^+$  60278), respectively. Alkalinity (bicarbonate) was measured by HCl titration. Chlorides were determined by the argentometric method. Indicator organisms viz. fecal coliform (FC), total coliform (TC) and heterotrophic plate count (HPC) were enumerated as per the procedure given in Standard Methods (APHA, 1998) via membrane filtration technique. Herein appropriately diluted ( $10^{-3}$ – $10^{-7}$ ) sample (100 ml in volume), in triplicate, were filtered through 0.45  $\mu\text{m}$  membrane filters and subsequently these filters were mounted on specific media supplied from Hi Media Laboratory Pvt. Ltd., India. Plates were then incubated for 24 h at 44.5 °C on FC Agar (M1122) medium for FC, 24 h at 37 °C on Endo agar (M029) for TC, and 24 h at 37 °C on HPC agar (M1097) for HPC. Results are reported as number of colony forming unit (CFU) 100 ml<sup>-1</sup>.

#### 4.2. Media analysis

Samples were augured from two levels; 5–10 cm and 20–30 cm, air dried and mixed in equal proportion to obtain a homogenous sample. Soil samples were then sub sampled and analyzed within 5–7 d, or stored at 4 °C and analyzed within 1 month. Air dried soil was then passed through 2 mm sieve and subjected to most of the physicochemical studies except for particle size analysis. Physicochemical characteristics included pH, moisture content, specific gravity, hydraulic conductivity, particle size analysis (Gee and Bauder, 1986), hydraulic conductivity, organic carbon

(Walkley and Black, 1934), CEC (Chapman, 1965), AEC (Mehlich, 1948). Exchangeable cations in the media such as  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{Al}^{3+}$ ,  $\text{Si}^{4+}$ ,  $\text{Fe}^{3+}$  were measured as per method given by Dubbin et al. (2006). ECEC was calculated as the sum of exchangeable cations. Nitrification potential of the media was measured as per Zhang et al. (2005).

Microbial characteristics included population of denitrifiers (Tiedje, 1994), nitrifiers and ammonia oxidizers (Schmidt and Belser, 1994). The number of proteolytic bacteria was estimated using casein/milk powder medium (Kern and Idler, 1999) and actinomycetes using starch casein medium (Wellington and Toth, 1994). The presence or absence of protozoan population such as flagellates, amoeba and ciliates in a mixture of soil with incubation media was noted using 20–45 $\times$  magnification with phase contrast microscopy (Leica DM LS2 series) and density of the protozoan was calculated using Most Probable Number table (Ingham, 1994).

Trace element concentrations in the medium were determined by X-ray fluorescence (XRF) spectroscopy on pressed powder pellets using a Philips PW 2404 instrument.

#### 5. Results and discussion

Results are expressed as arithmetic mean; however TC and FC are expressed as geometric mean. The standard deviations and means for all variables were performed by Statistica package for Windows (Version 5.1 Edition 98). Physicochemical contaminant removal is given in Table 2. Fig. 2a–g describes the monthly pattern for physicochemical contaminant removal.

During the period of 9 months monitoring, large variations in the influent parameters were observed; consequently, large variations in the effluent values were observed.

Table 2  
Physicochemical performance of CSF plant

Parameter	Site I			Site II		
	Influent	Effluent	% Removal	Influent	Effluent	% Removal
pH (range)	6.7–7.3	6.7–7.5		6.8–7.8	7.3–7.9	
Dissolved oxygen (mg l <sup>-1</sup> )	0.8 ± 1.1	3.7 ± 0.5		0.7 ± 1.0	4.0 ± 0.9	
Total dissolved solids (mg l <sup>-1</sup> )	405 ± 128	393 ± 105		493 ± 66	433 ± 63	
Conductivity ( $\mu\text{S cm}^{-1}$ )	604 ± 191	587 ± 158		736 ± 98	646 ± 93	
Suspended solids (mg l <sup>-1</sup> )	203 ± 148	13 ± 12	93	136 ± 75	18 ± 12	86
Volatile suspended solids (mg l <sup>-1</sup> )	112 ± 82	0.6 ± 1.9	98	79 ± 47	1.0 ± 3.2	98
Turbidity (NTU)	124 ± 81	8 ± 4	93	84 ± 42	10 ± 6	87
COD (mg l <sup>-1</sup> )	205 ± 129	38 ± 27	81	131 ± 40	39 ± 26	69
BOD (mg l <sup>-1</sup> )	125 ± 74	11 ± 9	90	82 ± 31	10 ± 10	86
Alkalinity (mg l <sup>-1</sup> )	146 ± 7	113 ± 18	22	153 ± 52	104 ± 33	31
Chlorides (mg l <sup>-1</sup> )	53 ± 22	48 ± 21	10	65 ± 18	63 ± 21	2
<i>Nitrogen</i>						
Nitrate-N (mg l <sup>-1</sup> )	3.0 ± 3.2	4.7 ± 2.8		3.3 ± 2.3	5.9 ± 2.5	
Nitrite-N (mg l <sup>-1</sup> )	0.05 ± 0.03	0.32 ± 0.3		0.1 ± 0.2	0.4 ± 0.3	
Ammoniacal-N (mg l <sup>-1</sup> )	3.7 ± 2.2	0.7 ± 0.4	81	3.2 ± 2.6	0.5 ± 0.5	85
TKN (mg l <sup>-1</sup> )	5.7 ± 2.4	1.2 ± 0.5	78	5.3 ± 2.8	1.1 ± 0.5	79
Total N (mg l <sup>-1</sup> )	8.8 ± 3.8	6.2 ± 2.9	28	8.7 ± 4.4	7.3 ± 2.7	16
-Phosphate-P (mg l <sup>-1</sup> )	2.5 ± 1.4	0.9 ± 0.6	63	2.1 ± 0.9	0.9 ± 0.4	55

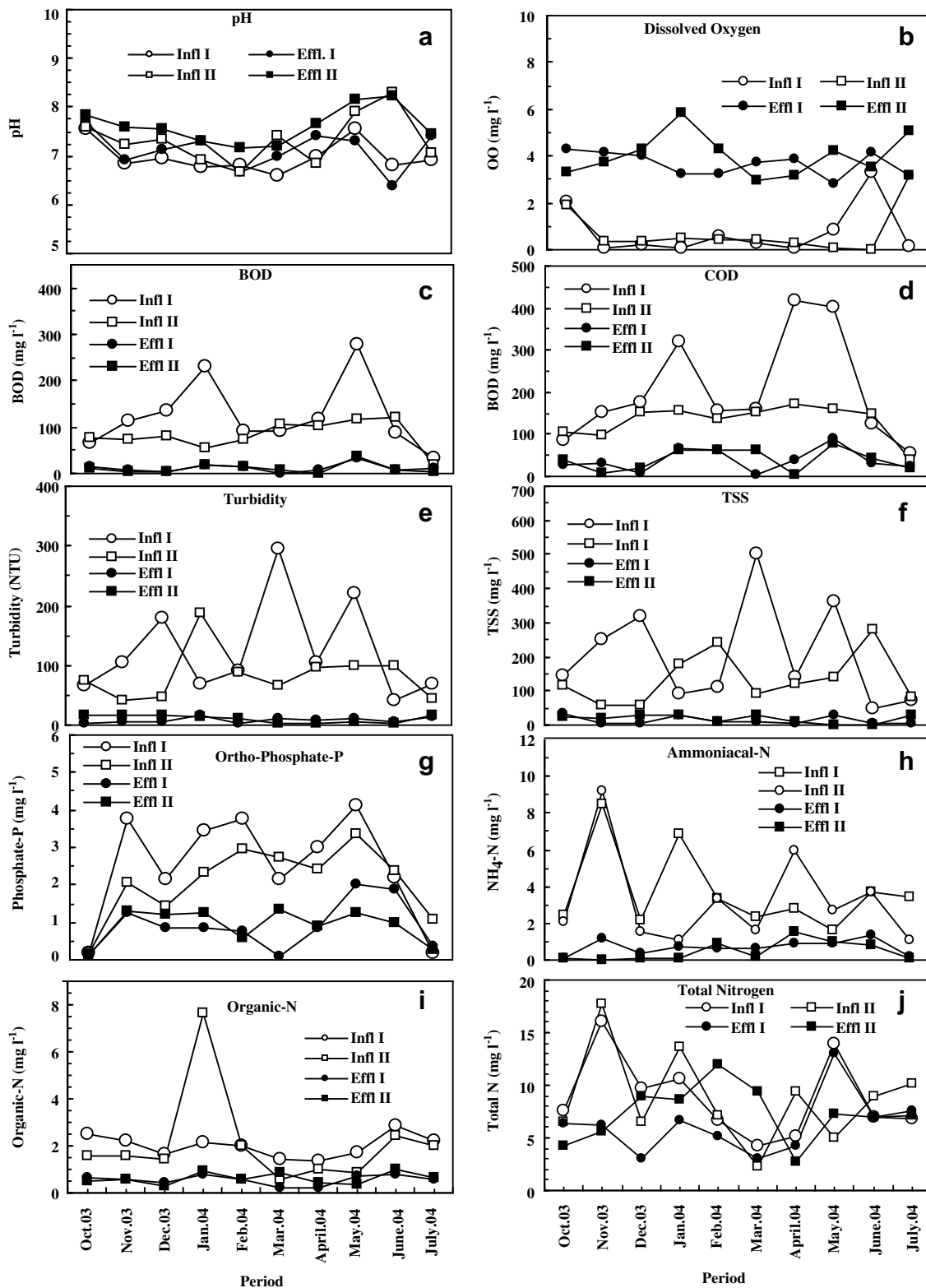


Fig. 2. Monthly monitoring of physicochemical contaminant removal of site I and II; profile of: (a) pH; (b) dissolved oxygen; (c) BOD; (d) COD; (e) turbidity; (f) total suspended solids; (g) *ortho*-phosphate-P; (h) ammoniacal-N; (i) organic-N; (j) total-N.

### 5.1. Physicochemical removal performance

Influent and effluent pH for both the sites were found to be 7.0–7.3 and 7.1–7.6 showing buffering capacity of CSF

environment. All the effluent analysis show significant increase in DO levels (3.7–4.0 mg l<sup>-1</sup>). Influent BOD was found to be 80–125 mg l<sup>-1</sup> and effluent levels were reduced to 11 ± 9 and 10 ± 10 mg l<sup>-1</sup>, respectively. Mean COD in

the raw sewage for both the sites were of the order of 134–205 mg l<sup>-1</sup>. Site I registered high incoming COD of 205 ± 129 mg l<sup>-1</sup>. Mean effluent COD levels were 38 ± 27 and 39 ± 26 mg l<sup>-1</sup>.

TSS concentration in the raw sewage were 203 ± 148 and 136 ± 75 mg l<sup>-1</sup>, respectively which were largely reduced to 13 ± 12 and 18 ± 12 mg l<sup>-1</sup> registering 94% and 87% removal. VSS concentration in the final effluent reduced from 79–112 to 0.6–1.0 mg l<sup>-1</sup> for both sites showing almost 99% removal. Similarly, turbidity was reduced to 8 ± 4 and 10 ± 6 NTU.

Chloride values change marginally from 53 ± 22 to 48 ± 21 mg l<sup>-1</sup> and from 65 ± 18 to 63 ± 21 mg l<sup>-1</sup> for site I and II. Similarly, total alkalinity changes from 146–153 to 105–114 mg l<sup>-1</sup>.

### 5.2. Nutrient removal

*ortho*-Phosphate-P concentrations in the raw sewage were 2.5 ± 1.4, and 2.1 ± 0.9 mg l<sup>-1</sup> for both sites, respectively. Phosphate-P levels reduced to 0.9 ± 0.6 and 0.9 ± 0.4 mg l<sup>-1</sup>.

Seasonal variations of nitrogen levels for both the sites are shown in Fig. 2h–j. NH<sub>4</sub><sup>+</sup>-N concentrations in the raw sewage were 3.2–4.7 ± 2.6 mg l<sup>-1</sup>. This concentration is quite low compared to typical quoted values of 12 mg l<sup>-1</sup> (Metcalf and Eddy, 2003). Removal was 82–85% with 0.7 ± 0.4 and 0.5 ± 0.5 mg l<sup>-1</sup> in the outlet. The mean NO<sub>3</sub><sup>-</sup>-N concentrations in the raw sewage were 3.0 and 3.3 mg l<sup>-1</sup> even though nitrate is typically absent in domestic sewage (Metcalf and Eddy, 2003). NO<sub>3</sub><sup>-</sup>-N levels in the outlet increased to 4.7 and 5.9 mg l<sup>-1</sup> implying nitrification at work. Similarly, mean NO<sub>2</sub><sup>-</sup>-N levels in the raw sewage were 0.05–0.1 mg l<sup>-1</sup> and found to increase to 0.3–0.4 mg l<sup>-1</sup> in the effluent.

Organic nitrogen was estimated by subtracting the concentration of NH<sub>4</sub><sup>+</sup>-N from TKN. Organic nitrogen levels were lower than ammonium levels which is the characteristic of sewage; implying no other source of nitrogen. Organic N levels in the raw were 2.0 ± 0.5 and 2.1 ± 2.0 mg l<sup>-1</sup>, respectively, and outlet shows reduction to 0.5 ± 0.2 and 0.6 ± 0.2 mg l<sup>-1</sup>. Site I has shown 73% removal followed by 42% removal for site II.

TN concentrations in the raw sewage were 8.8 ± 3.8, and 8.7 ± 4.4 mg l<sup>-1</sup>, respectively (Table 2). Effluent TN reduced to 6.2 ± 2.9, and 7.3 ± 2.7 mg l<sup>-1</sup> registering 28 and 16% removal.

### 5.3. Pathogen removal

Seasonal data of pathogen removal for both the site is reported here (Table 3). The average TC levels in the influent were (0.4–1.1) × 10<sup>8</sup> for both the site and reduces to (0.1–3.0) × 10<sup>5</sup> CFU 100 ml<sup>-1</sup> registering log removal (*K*) 2.6 and 3.5, respectively. FC levels reduces from 1.1 × 10<sup>7</sup> to 6.8 × 10<sup>4</sup> and from 6.5 × 10<sup>6</sup> to 6.7 × 10<sup>3</sup> CFU 100 ml<sup>-1</sup> showing *K* value of 2.2 and 3.0, respectively. The HPC counts reduces from 7.4 × 10<sup>8</sup> to 1.6 × 10<sup>6</sup> and 4.5 × 10<sup>8</sup> to 3.3 × 10<sup>5</sup> CFU 100 ml<sup>-1</sup> showing *K* value of 2.7 and 3.1 for both the sites. FC removal shows high *K* value of 2.5 for site I during summer 2004 and 4.6 for site II during monsoon 2004. *K* values for TC (2.7) and HPC (3.0) were reported during monsoon 04 and post monsoon 2003, respectively, for site I. Site II shows highest *K* value of 4.9 during monsoon 2004 for TC removal. Overall, Monsoon 04 shows better *K* for site II as compared to that of site I.

Laboratory Residence Time Distribution studies show media residence time of 10–20 min for the bed under operating conditions. Consequently all first order removal rate constants for pathogens are quite large; typically 1–2 h<sup>-1</sup> much larger than reported so far, similarly for other water quality parameters (Kadam, 2007).

The physicochemical environment (pH, moisture content, organic matter, CEC, AEC, etc.), hydrodynamic profile (oxygen concentration, residence time in filter) and microbial niche control the fate of microbes when applied on to the soil (Reddy et al., 1981; Crane and Moore, 1984). Pathogen removal in CSF system is due to (i) property of media to retain pathogens in first phase of filtration, i.e. bacterial adhesion, (ii) physicochemical environment of CSF and (iii) predation of these pathogens by predator population (Table 4) regenerating the bed for further adhesion.

### 5.4. Media characteristics

Table 4 summarizes the physicochemical, microbial and mineralogical characteristics of the media. The

Table 3  
Microbial performance of sites I and II

Org.	Site	Post Monsoon 03		Summer 04		Monsoon 04		Average	
		Influent <sup>a</sup>	Effluent <sup>a</sup>	Influent <sup>a</sup>	Effluent <sup>a</sup>	Influent <sup>a</sup>	Effluent <sup>a</sup>	Influent <sup>a</sup>	Effluent <sup>a</sup>
TC	I	7.5 × 10 <sup>7</sup>	2.1 × 10 <sup>5</sup>	1.5 × 10 <sup>8</sup>	4.9 × 10 <sup>5</sup>	1.2 × 10 <sup>8</sup>	2.4 × 10 <sup>5</sup>	1.1 × 10 <sup>8</sup>	3.0 × 10 <sup>5</sup>
	II	4.7 × 10 <sup>6</sup>	1.0 × 10 <sup>3</sup>	3.2 × 10 <sup>7</sup>	2.4 × 10 <sup>4</sup>	6.0 × 10 <sup>9</sup>	8.4 × 10 <sup>4</sup>	3.9 × 10 <sup>7</sup>	1.2 × 10 <sup>4</sup>
FC	I	8.1 × 10 <sup>6</sup>	7.8 × 10 <sup>4</sup>	1.7 × 10 <sup>7</sup>	5.2 × 10 <sup>4</sup>	6.8 × 10 <sup>6</sup>	8.5 × 10 <sup>4</sup>	1.1 × 10 <sup>7</sup>	6.8 × 10 <sup>4</sup>
	II	7.2 × 10 <sup>5</sup>	3.9 × 10 <sup>3</sup>	6.0 × 10 <sup>6</sup>	6.6 × 10 <sup>3</sup>	7.5 × 10 <sup>8</sup>	2.1 × 10 <sup>4</sup>	6.5 × 10 <sup>6</sup>	6.7 × 10 <sup>3</sup>
HPC	I	5.4 × 10 <sup>8</sup>	5.9 × 10 <sup>5</sup>	5.3 × 10 <sup>8</sup>	2.2 × 10 <sup>6</sup>	2.7 × 10 <sup>9</sup>	6.5 × 10 <sup>6</sup>	7.4 × 10 <sup>8</sup>	1.6 × 10 <sup>6</sup>
	II	2.4 × 10 <sup>8</sup>	1.1 × 10 <sup>5</sup>	3.2 × 10 <sup>8</sup>	4.2 × 10 <sup>5</sup>	6.0 × 10 <sup>9</sup>	1.1 × 10 <sup>6</sup>	4.5 × 10 <sup>8</sup>	3.3 × 10 <sup>5</sup>

<sup>a</sup> Colony forming unit (CFU) 100 ml<sup>-1</sup>; org: organism, TC: total coliform; FC: fecal coliform; HPC: heterotrophic plate count.

Table 4  
Properties of the media

Properties	I	II
<i>Physical properties</i>		
Moisture content (%)	29.9 ± 4.1	23.0 ± 3.2
Conductivity (µS cm <sup>-1</sup> )	1164 ± 33	260 ± 11
TDS (mg l <sup>-1</sup> )	780 ± 22.1	175 ± 7.4
Temp (°C)	26.7 ± 0.3	25.6 ± 0.2
<i>Particle size distribution</i>		
Clay (g kg <sup>-1</sup> )	230 ± 10	160 ± 12
Silt (g kg <sup>-1</sup> )	250 ± 12	400 ± 17
Sand (g kg <sup>-1</sup> )	400 ± 18	380 ± 13
Gravel (g kg <sup>-1</sup> )	120 ± 7	60 ± 6
Soil texture (USDA Scheme)	Loam	Loam
Bulk density (g cm <sup>-3</sup> )	1.39	1.44
Hydraulic conductivity, $K_L$ (m s <sup>-1</sup> )	3.69 × 10 <sup>-6</sup>	2.54 × 10 <sup>-6</sup>
<i>Chemical properties</i>		
pH (range)		
Soil suspension (1:5)	6.4–6.6	6.6–7.0
Soil paste	6.4–6.6	7.0–7.2
Soil-KCl	5.8–6.2	6.2–6.6
Oxidizable organic matter (g C kg <sup>-1</sup> )	14.6 ± 1.4	20.3 ± 2.1
Total organic carbon (g C kg <sup>-1</sup> )	19.4 ± 1.9	26.9 ± 2.8
Organic matter (g C kg <sup>-1</sup> )	29.1 ± 2.8	40.5 ± 4.2
Carbon (g kg <sup>-1</sup> )	36 ± 2.2	47.1 ± 3.0
Hydrogen (g kg <sup>-1</sup> )	11.8 ± 0.2	11.3 ± 0.2
Nitrogen (g kg <sup>-1</sup> )	5.2 ± 0.2	6.0 ± 0.2
C/N	6.89 ± 0.21	7.8 ± 0.44
CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	58.27 ± 5.0	32.0 ± 5.5
ECEC (meq 100 g <sup>-1</sup> )	31.14 ± 0.53	27.66 ± 3.95
AEC (cmol <sub>c</sub> kg <sup>-1</sup> )	2.70 ± 0.5	2.5 ± 0.3
BET surface area (m <sup>2</sup> g <sup>-1</sup> )	9.1 ± 0.6	4.0 ± 0.3
Nitrification potential (mg N kg <sup>-1</sup> h <sup>-1</sup> )	9.1 ± 0.9	(32 ± 9.0) × 10 <sup>-3</sup>
<i>Microbial ecology</i>		
Ammonia oxidizers (cells g <sup>-1</sup> )	2.2 × 10 <sup>7</sup>	8.9 × 10 <sup>6</sup>
Nitrifiers (cells g <sup>-1</sup> )	2.0 × 10 <sup>7</sup>	8.9 × 10 <sup>7</sup>
Denitrifiers (cells g <sup>-1</sup> )	4.0 × 10 <sup>7</sup>	8.9 × 10 <sup>7</sup>
Proteolytic bacteria (cells g <sup>-1</sup> )	5.3 × 10 <sup>9</sup>	9.0 × 10 <sup>9</sup>
Actinomycetes (cells g <sup>-1</sup> )	2.4 × 10 <sup>8</sup>	2.5 × 10 <sup>8</sup>
Heterotrophic plate count (cells g <sup>-1</sup> )	3.2 × 10 <sup>12</sup>	3.0 × 10 <sup>13</sup>
<i>Protozoa</i>		
Naked amoebae (cells g <sup>-1</sup> )	1.0 × 10 <sup>8</sup>	1.0 × 10 <sup>8</sup>
Flagellates (cells g <sup>-1</sup> )	1.0 × 10 <sup>8</sup>	4.9 × 10 <sup>4</sup>
Ciliates (cells g <sup>-1</sup> )	1.4 × 10 <sup>5</sup>	8.3 × 10 <sup>4</sup>
<i>Mineral properties</i>		
Al <sub>2</sub> O <sub>3</sub> (%)	8.8 ± 0.05	8.52 ± 0.3
CaO (%)	4.3 ± 0.1	4.73 ± 0.15
K <sub>2</sub> O (%)	0.24 ± 0.01	0.23 ± 0.01
MgO (%)	1.91 ± 0.01	1.6 ± 0.04
SiO <sub>2</sub> (%)	31.5 ± 0.39	29.07 ± 1.21
Fe <sub>2</sub> O <sub>3</sub> (%)	13.3 ± 0.02	12.2 ± 0.02
Na <sub>2</sub> O (%)	0.74 ± 0.01	0.53 ± 0.03
TiO <sub>2</sub> (%)	1.95 ± 0.03	1.74 ± 0.06
MnO (%)	0.25 ± 0.08	0.16 ± 0.001
P <sub>2</sub> O <sub>5</sub> (%)	0.48 ± 0.01	0.65 ± 0.01

moisture content for both the media was in the range of 23–29% which shows that media drains rapidly. The  $K_L$  values measured as per standard protocol for both the media were of the order of 10<sup>-6</sup> m s<sup>-1</sup>. The values of organic matter, total carbon and nitrogen content, CEC, AEC are consistent with reported value for soils irrigated

with municipal wastewater for prolonged period (Fuentes et al., 2002). CEC and AEC of the site I is comparatively larger than site II. Site I presents more BET surface area (9.0 m<sup>2</sup> g<sup>-1</sup> as against 4.0 m<sup>2</sup> g<sup>-1</sup>) reflecting more adsorptive area.

The microbial ecology in place is quite rich in terms of ammonia oxidizers, nitrifiers, denitrifiers, proteolytic bacteria, actinomycetes, heterotrophic and predator population (protozoa and geophagus worm). These values are far exceeding the values reported in the literature (McCarthy, 1987). Microbial ecology of the two media is not much different and is the characteristic feature of CSF media formulation (Shankar et al., 2005).

Table 4 also shows the composition of medium as determined by XRF. Site I in comparison to site II shows high amount of Al, K, Mg, Na, Ti, Fe, and silicate. Presence of these exchangeable cations is also reflected in the effective CEC (ECEC) values.

Specific mass loading for BOD and COD was 15.6 and 25.6 g m<sup>-2</sup> d<sup>-1</sup> for site I and 16.5 and 26.3 g m<sup>-2</sup> d<sup>-1</sup> for site II, respectively. This performance is in line with the age of the sites; the older the better. Log removal for TC, FC and HPC were in the range of 2.4–2.7 for site I and 2.7–3.1 for site II, respectively.

## 6. Conclusions

The CSF plants show high COD, BOD, Ammoniacal-N, Nitrite-N, SS, Turbidity, and pathogen removal. Comparison of performance of the two sites shows that CSF matures with age. Summing up, the unique features of CSF are low hydraulic retention time, high hydraulic loading, no pretreatment, high DO levels in the effluent, significant BOD, COD and pathogen removal, no sludge production, no mechanical aeration, very low energy requirement (0.04 kW h m<sup>-3</sup>) and ever green ambience.

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