Vermifilters: a tool for aerobic biological treatment of herbal pharmaceutical wastewater

Sharda Dhadse, Shanta Satyanarayan, P. R. Chaudhari and S. R. Wate

ABSTRACT

Herbal pharmaceutical wastewater possesses high chemical oxygen demand (COD) (21,960–26,000 mg/l) and biochemical oxygen demand (BOD) (11,200–15,660 mg/l) and suspended solids (SS) (5,460–7,370 mg/l). It cannot be directly discharged into surface water bodies, due to its highly biodegradable nature. Herbal pharmaceutical wastewater has been treated by using vermifilter, which is an ecosystem consisting of biosoil with bacteria and earthworms producing vermicastings. In the present studies a cost-effective, eco-friendly and sustainable method has been applied for the treatment of herbal pharmaceutical wastewater using earthworms. Studies were carried out at different organic loadings, ranging between 0.8 and 3.2 kg COD/m^3day at three different hydraulic loadings of 1, 2 and 4 days. Vermifilters packed with 1:1:1 ratio of soil, sand and vermicast as media matrix along with the twenty adult earthworms in each reactor was used for the experiments. Treated effluent was colour and odour free. Efficient COD/BOD removals in the range of 85.44%–94.48% and 89.77%–96.26% were obtained respectively at 2 days hydraulic retention time (HRT). Heavy metal removals were also observed and no sludge production problem was encountered, only nutrient rich vermicast from the filters were removed and analysed after the experiments. It showed higher manurial value than control in terms of available nitrogen, phosphorus and potassium (NPK) and were in the range of 178.75–278.75 Kg/hectare available nitrogen, 16.128–50.4 kg/hectare of available phosphorus and 19.3–28.6 kg/hectare of available potassium at maximum HRT and at different organic loadings. This paper discusses in detail the feasibility of vermifilters in herbal pharmaceutical wastewater treatment at different organic and hydraulic loadings.

Key words | chemical oxygen demand, earthworms, *Eudrilus eugenie*, herbal pharmaceuticals, vermicast, vermifilter

Sharda Dhadse (corresponding author)
P. R. Chaudhari
S. R. Wate
Environmental Impact Assessment Division,
National Environmental Engineering Research Institute,
Nagpur 440020,
India
E-mail: *sharda_dhadse@yahoo.com*

Shanta Satyanarayan
Wastewater Treatment Division,
National Environmental Engineering Research Institute,
Nagpur 440020,
India

INTRODUCTION

Herbal pharmaceutical medicines are being used by about 80% of the world population especially in Southeast Asian countries including India. According to world health organization (WHO) in both developed and developing countries a considerable percentage of people use medicinal plants as remedies and the number is on the increase (Jaggi 1984; Mukharjee & Subbarayappa 1984; Pushpangadan *et al.* 1997; Export Development Organization Report 2001; Vanerkar *et al.* 2005*a*,*b*).

This wastewater has been treated using biological and physicochemical treatment methods, but during biological treatment, the system gets hampered due to fluctuating load, which is due to the batch production of medicines and use of different raw materials. Few papers on the treatment of herbal pharmaceutical wastewater by anaerobic fixed film fixed bed reactors have been reported (Naphde *et al.* 1983; Nandy *et al.* 1989; Mukti Debroy *et al.* 1993).

doi: 10.2166/wst.2010.523

One of the suitable treatment technologies, which seemed viable to reduce the pollution to the tune of 50% to 60% in terms of COD and 55% to 65% BOD is the physico-chemical treatment (Vanerkar *et al.* 2005*a*,*b*). A news item reported that industrial effluents could be treated by vermitechnology (Bhawalkar 1995; The Hitvada 2003). The work on the wastewater treatment by vermitechnology is being carried out at an Australian university, wherein the gray water is applied to composting process in low cost aerobic treatment system. Studies are reported on the quality of compost harvested from grease trap and sand filter, but actual wastewater treatment has not been discussed (Okalebo 2004).

Municipal sewage treatment using vermifilter packed with 1:1 ratio of soil and sand, using earthworms has been reported (Taylor *et al.* 2003; Ztiu *et al.* 2003). No research on industrial wastewater treatment by vermifilter has been recorded. Whatever work is reported is on the use of industrial wastewater in composting process only. Hence an attempt has been made to treat the herbal pharmaceutical wastewater by vermitreatment technology at various organic and hydraulic loading rates.

MATERIALS AND METHODS

Wastewater was collected from a herbal pharmaceutical manufacturing unit, whose production capacity was around 196 tonnes/year. Samples were collected on hourly basis and composited for 24 hours to get a uniform homogenized wastewater. Detailed characterization of the wastewater was carried out along with routine physico-chemical parameters including important heavy metals as per the standard methods (Standard Methods 1998). Heavy metals were estimated using ICP analyser. A total of four filter units needed for the experiments were fabricated out of glass columns in the institute's glass blowing division. Capacities of the filter were around 1,050 ml total volume each. While the working volume was around 850 ml. Filters were packed with 1:1:1 ratio of sand, vermicast and fine soil. The particle size was approximately around 0.4 mm thus providing a surface area of 600 m^2/gm with voidage of 55%. Filters were operated at down flow mode, which prevents flooding of the reactor. Studies were carried out for a period of one year. Earthworm species of *Eudrilus eagenie* were used in the experiments. Required earthworms were procured from a culturing farm being maintained by an NGO at Nagpur, Maharashtra, India.

Flow to the filter was controlled at a required flow rate using Watson–Marlow Pumps. Different organic loadings of 0.8, 1.6, 2.4 and 3.2 kg COD/m^3day with different hydraulic loadings of 1, 2 and 4 days were studied in detail. The above loadings are on higher side for a aerobic system but being a natural system, earthworm could sustain these loading

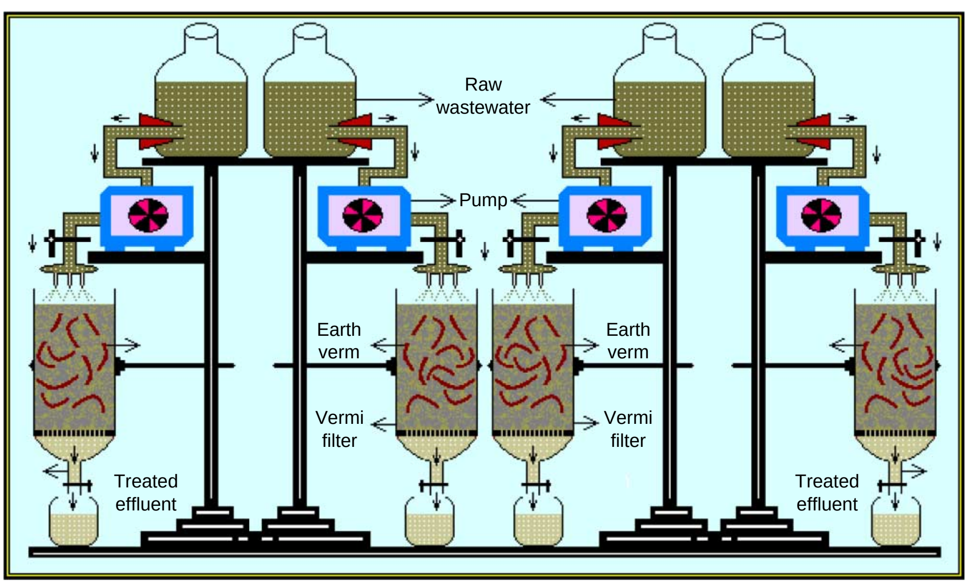

Figure 1 | Experimental Setup.

rates. During the study period no death of earthworms were observed. In each column twenty fully grown, healthy earthworms were added. The experimental setup is shown in Figure 1).

RESULTS AND DISCUSSION

The raw wastewater generated in the different processes is highly acidic with pH ranging between 3.6–4.2. Being acidic in nature the wastewater requires neutralization prior its use in the experiment. The lime (4.2 gm/l) was used to neutralize the wastewater. Physico-chemical characteristic of raw and neutralized wastewater is shown in Table 1.

Herbal Pharmaceutical wastewater depicts large variations in COD/BOD/SS, total nitrogen and other parameters. This is due to the process variation i.e. batch system or continuous system, raw material consumption, use of different additives in different drug preparation and also based on the medicine i.e. liquid or solid.

After the addition of earthworms in vermifilters slow addition of wastewater was initiated using a flow meter. Once the filters were stabilized as was seen from constant COD reductions, treated effluent from the columns was collected for a period of six days and composited at every organic loading. Combined effluent was analysed regularly. Initially a hydraulic loading of one day was used. Gradually the hydraulic loading was increased to 2 and 4 days. Physico-chemical characteristics of treated effluents are indicated in Table 2.

pH of the treated effluents ranged between 8.25–8.54, 7.8–8.2 and 7.5–8.0 for 1.0, 2.0 and 4.0 days hydraulic loading respectively, indicating good buffering in the system. Treated effluents depicted no colour or odours, Effluents were very clear. Original raw water depicted dark grey colour.

Total dissolved solids in the initial neutralized sample varied between 2,680 and 4,474 mg/l. While in the treated effluents it reduced efficiently with reduction varying between 77%–82.66% at 4 days HRT and loading range of 0.8 and 3.2 kg COD/m^{3}day. Whereas TDS reduction of 90–92% has been reported for treated municipal sewage from a vermifilter (Ztiu *et al.* 2003). This higher TDS removal can be attributed to original low TDS present in the sewage, which is generally in the range of 435–450 mg/l while in the present study the TDS were on higher side. Inspite of this higher TDS even at one day HRT the TDS removal varied between 73.0 and 79.0% at lowest and highest loadings, which is indicating good filter efficiency. Suspended solids removals were more than 95% irrespective of different hydraulic detention times. This may be due to general biodegradion of organic waste in the wastewater and also due to filtration and adsorption. Effluents were very clear and odour free. Suspended solids are also trapped

Table 1 | Physico-chemical characteristics of combined herbal pharmaceutical wastewater, raw and neutralized

Sr. No.	Parameters	Raw wastewater	Neutralized wastewater
1	pH	3.9–4.0	6.8–7.4
2	Colour (Visual)	Dark Yellow	Black
3	Total acidity	3000	–
4	Total suspended solids	5460–7370	3320–4864
5	Total dissolved solids	2564–3660	2680–4474
6	Total solids	8024–11030	6230–9340
7	Chemical oxygen demand	21960–26000	17400–20000
8	Biological oxygen demand	11200–15660	9370–11910
9	Sulfide as ($S^{-}2$)	42–54	38–42
10	Sulphates as (SO_4^{-2})	82–88	68–72
11	Total phosphates	260–280	220–242
12	Total nitrogen	389–498	336–378
13	Oil and grease	140–182	75–98
14	Sodium	155–266	114–250
15	Potassium	128–140	118–132
16	Heavy Metals		
	Iron (Fe)	65.6–65.7	26.2–41.4
	Copper (Cu)	1.67–0.649	0.081–1.42
	Manganese (Mn)	8.47–6.41	3.22–5.87
	Nickel (Ni)	2.35–0.892	0.107–1.49
	Zinc (Zn)	0.583–0.608	0.215–0.414
	Chromium (Cr)	1.11–0.057	0.051–0.456
	Lead (Pb)	6.53–0.559	0.460–4.08
	Cadmium (Cd)	0.484–0.036	0.032–0.339
	Selenium (Se)	0.666–0.428	0.121–0.397
	Arsenic (As)	0.0076–0.0049	0.0023–0.0040

All values are expressed in mg/l except pH and colour.

Table 2 | Physico-chemical characteristics of effluent from different organic loadings, (Flow Rate 850, 425, 213 ml/day)

	Parameter	**Organic loading Kg COD/m^3 day**											
		0.8			**1.6**			**2.4**			**3.2**		
Sr. No.	**HRT (days)**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**
1	pH	8.0	8.2	8.54	7.8	8.0	8.42	7.7	7.9	8.34	7.5	7.8	8.25
2	Alkalinity	292	373	422	299	312	447	328	438	488	348	466	536
3	Turbidity	0.92	0.88	0.62	0.99	1.23	0.84	1.16	1.65	0.90	1.24	1.82	0.97
4	Total dissolve solids	720	666	620	905	805	742	928	860	760	964	900	820
5	Suspended solids	62	44.0	32.6	86	64.0	46.4	98	77.0	58	108	86.0	67.0
6	Chloride	48	39	29	76	64	56	84	71	62	97	86	72
7	Sulphate	5.9	4.8	3.6	10.8	8.6	6.4	28.6	17.1	12.8	26.8	18.6	14.6
8	Sodium	96.5	85.5	72.6	126	118	82.0	164	136	106	178	168	124
9	Potassium	32	29	25.0	39	33	28.0	44	38	35	53	49	42
10	Nitrate nitrogen	0.16	0.14	0.12	0.39	0.36	0.26	0.88	0.82	0.62	0.92	0.89	0.78
11	Total nitrogen	1.20	1.40	1.68	1.34	1.58	1.82	1.48	1.66	1.99	1.64	1.82	2.0
12	Total phosphate	0.24	0.26	0.29	0.50	0.54	0.66	0.58	0.62	0.72	0.77	0.82	0.91
13	COD	53	69	78	132	181	260	250	381	516	398	703	898
14	%CODr	91.5	94.48	96.88	89.06	92.50	94.62	86.20	89.47	92.86	83.52	85.44	90.68
15	BOD	19	26	38	53	70.0	98	108	178.0	190	196	367	378
16	%BODr	94.5	96.26	97.32	92.16	94.76	96.36	89.34	92.53	95.30	85.50	89.77	92.99
17	Heavy metals												
	Zinc (Zn)	0.296	0.217	0.208	0.308	0.220	0.210	0.326	0.228	0.218	0.355	0.232	0.221
	Lead (Pb)	0.862	0.836	0.832	0.899	0.876	0.862	1.223	1.200	1.190	1.278	1.262	1.230
	Cadmium (Cd)	0.236	0.228	0.224	0.287	0.252	0.246	0.299	0.283	0.279	0.388	0.386	0.373
	Nickel (Ni)	0.210	0.199	0.195	0.236	0.220	0.217	0.272	0.263	0.258	0.316	0.311	0.309
	Cobalt (Co)	0.164	0.155	0.148	0.171	0.157	0.151	0.202	0.196	0.191	0.254	0.248	0.242
	Manganese (Mn)	0.243	0.227	0.224	0.251	0.234	0.230	0.268	0.262	0.255	0.283	0.274	0.269
	Iron (Fe)	0.464	0.441	0.439	0.532	0.523	0.515	0.544	0.530	0.529	1.022	0.992	0.985
	Chromium (Cr)	0.318	0.311	0.307	0.426	0.409	0.402	0.610	0.599	0.593	1.354	1.333	1.326
	Copper (Cu)	0.154	0.142	0.139	0.159	0.145	0.140	0.169	0.161	0.157	0.172	0.165	0.161
	Arsenic (As)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Above readings are the average of six sets.

All the parameters are expressed in mg/l except, pH, turbidity, conductivity and percentage reduction.

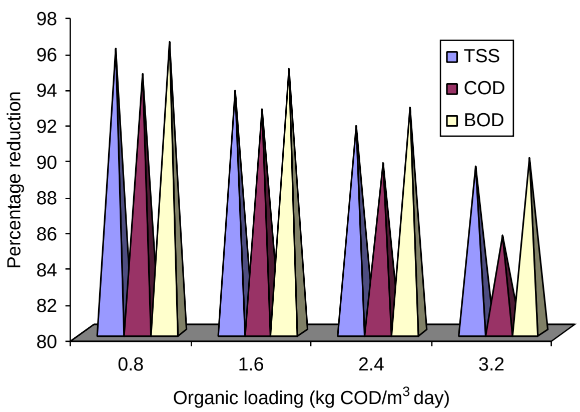

Figure 2 | Percent reduction of TSS, COD and BOD at 2 day Hydraulic Retention Time (HRT).

on top of the filter when the wastewater trickles through the filter column and later the SS is processed and broken in to finer particle size by the earthworms, makes it easier for the microorganism immobilized on soil medium to ingest it.

Organic removals in terms of COD and BOD were appreciable even at one day HRT and at highest loading of 3.2 kg COD/m^3 day, the COD/BOD removals were 83.52% and 85.50% respectively, while at 0.8, 1.6 and 2.4 kg COD/m^3 day loading COD/BOD removals were 91.5% and 94.5%, 89.0% and 92.16% 86.20% and 89.34% respectively. For the removal of COD/BOD/TSS the 2 day HRT is observed to be most optimum one (Figure 2). Earthworm depicted good efficiency in degrading the organic impurities. Earthworms present in the filter, by their burrowing movements provide good aeration to the soil media matrix and also good population of aerobic microorganisms. Intensification of soil process and aeration by the earthworms enable the stabilization of wastewater and filtration efficiency becomes more effective. Earthworms also eat away the unwanted microorganism present in the wastewater. Due to rigorous movement of earthworm, good aeration and porosity is maintained in the filter preventing filter clogging and souring.

Vermifilter technology works very efficiently provided flow of wastewater is controlled meticulously and flooding of the filter is avoided. Studies indicated the organic loading of 3.2 kg COD/m^3 day also resulted in good efficient results. Absolute concentration of COD/BOD and SS were marginally higher than the stipulated standards in the final treated effluents. Simple aeration of the effluent or simple addition of dilute bleaching powder will take care of the marginal pollution in the effluent. Treated effluent can be used for irrigation, washing, horticulture and fire fighting.

Apart from the routine organic pollutant removal, heavy metal removals were also very efficient. Original neutralized wastewater depicted high concentration of iron (26.2–41.4 mg/l), copper (0.081–1.42 mg/l) and manganese (3.22–5.87 mg/l). But these heavy metals were removed and were well below the stipulated standards, except lead. Arsenic was completely removed. Heavy metals are reduced by uptake by the earthworms. (Sinha *et al.* 2005).

Among hydraulic loadings studied four days HRT definitely was superior. But the COD/BOD reduction showed marginal improvements than two days HRT. It is not worth doubling the HRT to get marginal increase in COD/BOD removals. It is hence preferable to use two days HRT only and organic loading of 3.2 kg COD/m^3 day. At this highest loading and two days HRT gives COD/BOD reductions of above 90%. Even at one day HRT the results obtained were good at lowest loading of 0.8 kg COD/m^3 day. While at highest loading of 3.2 kg COD/m^3 day resulted in 83.52% of COD and 85.50% BOD reduction. Depending on the required situation one day HRT and 3.2 kg COD/m^3 day loading can also be applied as a primary treatment to stabilize 80% the pollutants. This will reduce the load on secondary treatment system. This will also be a economically viable treatment system. But otherwise two days HRT and 3.2 kg COD/m^3 day is the optimum considering all other factors.

CONCLUSION

Based on the detail studies it can be concluded that vermitreatment (vermifilter) is a feasible option to treat herbal pharmaceutical wastewater. Final treated water is very clear and no odour exists. This treatment technology is very suitable as there is no sludge disposal problem encountered. More over the substrate is converted in to vermicast, a suitable manure for land application, as it is rich in nutrients. The vermitreatment of herbal pharmaceutical wastewater is today the most cost effective, ecofriendly and most sustainable technology. This technology is very suitable for rural areas.

ACKNOWLEDGEMENTS

The authors are grateful to the Director, National Environmental Engineering Research Institute, (NEERI) for carrying out this research work.

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