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Vermitreatment of Pharmaceutical Wastewaters and Nutrient Bioassay of Treated Effluents for Reuse as Irrigation Water

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ABSTRACT: *Present investigation was undertaken to study the low cost efficient treatment system for the treatment of high organically polluted industrial wastewater. The herbal and bulk drug pharmaceutical industry wastewaters were characterized and treated by vermifilter units and the treated effluents were assessed for its toxicity or nutrient enrichment by algal assay procedure to explore the feasibility of use of treated effluents for the agriculture. Both the raw wastewaters were observed to be high strength organic wastewaters with very high COD and BOD_5 with dark yellow color. Results of study established vermitechnology as the low cost efficient method for the treatment of herbal and bulk drug pharmaceutical wastewaters. Significant observations were recorded with respect to reduction of color, heavy metals and pollutants, and stabilization of organic waste. The algal growth potential studies were carried out by using Scenedesmus bijugatus. The significant enhancement of algal growth in algal growth potential test indicated the value addition to the effluents during vermifiltration process in terms of nutrients and growth promoting factors. The effluents from low organic loading (0.8 kg COD/m3.d) unit complied with the Indian standard for irrigation water while the effluents from higher organic loading (3.2 kg COD/m^3.d) required further treatment for polishing. Vermifilter system was, thus, proved to be suitable for the treatment of organically polluted industrial effluents, for their value addition and making them suitable for further recycling and reuse in agriculture as aerial spray or a liquid manure to increase the productivity of crop.*

KEYWORDS: *Pharmaceutical Wastewater, Vermitechnology, Eudrilus eugeniae, Algal Bioassay*

I. INTRODUCTION

Pharmaceutical wastewater is high strength organically polluted industrial wastewater. The conventional treatment of pharmaceutical wastewater is highly technological and costly. Attempt has been made to use coagulants and synthetic polyelectrolytes for the treatment of herbal pharmaceutical wastewater [1, 2]. There is need to explore low cost method for the wastewater treatment, amenable to producing nutrient-rich effluent suitable for recycle and reuse for agricultural irrigation. Vermifilter is known to be simple and low-cost method for the stabilisation of waste organic residues producing high quality nutrient-rich vermiwash containing plant growth promoting factors. No one has used vermifilter for the treatment of pharmaceutical wastewater. Therefore, vermifilters were selected for the treatment of pharmaceutical wastewater.

Algal bioassay is the main tool in water pollution monitoring because algae are more sensitive for contamination than fish or invertebrates as test organisms. The nature of the effluents can be assayed by algae since the responses can be measured in terms of biomass production or through the metabolic response generated [3, 4, 5]. Toxicity of raw wastewaters treated by advanced oxidation processes namely Fenton and Photo-fenton reactions was evaluated by algal bioassay [6, 7, 8]. Present investigation envisages studying the treatment efficiency of vermifilters for treatment of herbal and bulk drug pharmaceutical wastewaters and their nutrient assay by algal growth potential (AGP) test.

II. MATERIALS AND METHODS

2.1 Vermi-treatment of Wastewaters

The laboratory scale model of vermifilters was fabricated using glass columns having 10 cm diameter and 45 cm length with an outlet at the bottom to collect effluents. The filters were operated on down-flow mode, using flow meters and Watson Marlow pump. The reactors were packed with 1:1:1 ratio of sand, soil and vermicast, leaving 6 cm of upper column empty for the distribution of wastewater. The particle size of the packing material ranged from 0.4 to 0.6 mm that provided surface area of 600 to 650 m^2/gm with voidage of 55%. The filters were operated at downflow mode which prevents flooding of the reactor. Earthworm species *Eudrilus eugeniae* was used in the experiment. A total of five reactors for each wastewater were used. The working volume of the filters was maintained at 850 ml. In every vermifilter a total of 15 healthy earthworms were introduced. Schematic of the experimental setup is shown in Fig. 1.

For both the wastewaters viz. bulk drug pharmaceutical wastewater (BDP) and herbal pharmaceutical wastewater (HPW), two day hydraulic retention time at 0.8 kg COD/m^3.d and 3.2 kg COD/m^3.d organic loadings rate was found to be the optimum. Therefore, the vermitreated effluents collected at these loadings, as described below, were selected for the algal bioassay to study its efficiency for the agricultural purpose.
BDL : Vermitreated bulk drug pharmaceutical effluent at low organic loading rate of 0.8 kg COD/m^3d
BDH: Vermitreated bulk drug pharmaceutical effluent at high organic loading rate of 3.2 kg COD/m^3d
HPL: Vermitreated herbal pharmaceutical effluent at low organic loading rate of 0.8 kg COD/m^3d
HPH: Vermitreated herbal pharmaceutical effluent at high organic loading rate of 3.2 kg COD/m^3d
The raw wastewater samples and effluent samples were analysed for their physico-chemical characteristics [9].

2.2 Algal Growth Potential Test

Algal growth potential (AGP) test was carried out using fresh water green alga *Scenedesmus bijugatus* (Fig. 2) as test organism, which was grown and maintained in basal medium (Table 1). Nutrient concentration in basal medium was treated as 100% nutrients for the alga. pH of basal medium was adjusted to 7.8 by 1% NaOH solution. *Scenedesmus* culture was isolated from clean lake water and grown in the basal medium. The stock culture was maintained in 2 litre flasks under 1500 lux light intensity. Every care was taken to keep them in sterile conditions.

2.3 Algal Inoculum

Required aliquots of exponentially growing stock of algal culture were centrifuged. The centrifuged biomass was washed with distilled water and again centrifuged. To this, required amount of distilled water was added so that 1 ml of this inoculum gave an optical density of 0.03 in test culture.

2.4 Procedure for Algal Bioassay

Clean, sterilized test tubes were used for AGP test. Three sets were prepared, first with serial dilutions of treated effluents with distilled water viz. 10% effluent, 20% effluent, 40% effluent, 60% effluent, 80% effluent and 100% effluent, second and third sets with same dilutions fortified with 30% and 100% basal medium nutrients respectively. Required amount of algal inoculum was added to each of the test tube in equal amount to give initial optical density of 0.03. Then the inoculated test tubes were kept in racks illuminated with cool white fluorescent tubes giving light intensity of 300 lux units. Algal growth was monitored in all the dilutions for 7 days period starting on 0 day. The growth of *Scenedesmus* was studied by "in-situ" measuring the optical density (OD) of the cultures by the spectrophotometer at the wavelength of 560 nm.
2.5 Estimation of Specific Growth Rate and Doubling Time
Specific growth rate of alga (1) and doubling time (2) were calculated as per the following method.
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$$\text{Specific growth rate } (\mu): \frac{\text{Final } (\log_2 \text{OD} + 10) - \text{Initial } (\log_2 \text{OD} + 10)}{\text{No. of days (Exponential growth period)}} \text{ --------- } (1)$$

$$\text{Doubling Time} = 1 / (\mu) \text{ -- } (2)$$

III. RESULTS AND DISCUSSION

3.1 Pharmaceutical Wastewaters

Physicochemical characteristics of HPW and BDP raw wastewaters are given in Table 2. Both the wastewaters were dark yellow in colour. HPW was acidic (pH 3.9-4.0) and BDP was near neutral (pH 7.5). Both the wastewaters were highly organic with very high COD and BOD_5 values and high concentration of total nutrients. The wastewaters also showed the presence of heavy metals. The BOD_5:COD ratio in these bulk drug and herbal pharmaceutical wastewaters ranged from 0.38 to 0.52 (Table 3). This range is near to 0.5 recorded for domestic wastewater. It is generally assumed that when this ratio is below 0.2, the wastewater/effluent is toxic. Thus these effluents are not toxic and may be used for irrigation. At the same time, the COD:BOD_5 ratio of these effluents varied from 1.92 to 2.65, which is near to ratio 2.5 for domestic wastewater and thus may be suitable for recycling as irrigation water in agriculture. It was observed that the physicochemical characteristics of bulk drug and herbal pharmaceutical effluent from low organic loading (0.8 kg COD/m^3.d) treatment unit comply with Indian standard for irrigation water (IS:2490 - 1982) (Table 4) and can be used for agricultural irrigation. The effluent from higher organic loading (3.2 kg COD/m^3.d) treatment units will require further treatment to refine the effluent quality with respect to dissolved solids, BOD_5 and Iron content.

3.2 Treatment Efficiency

The physicochemical characteristics of the treated effluents and the percentage reduction in the pollution indicator parameters are shown in Table 5. In both the effluents, pH has been improved to alkaline side, turbidity significantly reduced along with concomitant reduction in TSS by 91.6% to 93.6% in low organic loading and 83.1% to 89% in high organic loading. TDS was reduced by 64.2% to 75.92%. COD and BOD_5 reduction ranged from 83.34%to 96.26%. Similarly significant reductions were observed in chlorides, sulphides, sulphates, total phosphorus, total nitrogen, sodium, potassium, Pb, Cd, Ni, Co, Fe, Mn, Cr, and Cu. Though the overall reduction is satisfactory, it is observed that percent reductions in different parameters (except TDS) are more in low organic loading rate (0.8 kg COD/m^3.d) in both the effluents. Thus, the low organic loading to vermifilters gives better quality of effluent.

3.3 AGP Test with Different Dilutions of BDL and BDH with Distilled Water

The results of the AGP experiments with serial dilutions of BDL and BDH are shown in Tables 6 and 7. It has been observed that in both the effluents, the lag phase, exponential growth period are similar. In BDL, maximum exponential growth rate and standing crop enhancement on 7th day were in 40% dilution, while the same was maximum in 60% dilution of BDH effluent. However the 100% effluent also had better results with respect to exponential growth rate and doubling time and enhancement of standing crop on 7th day. These results indicate that both the effluents were having rich quantity of available nutrients and had stimulating effect significantly over the control and the BDL had maximum growth stimulatory effect than BDH. This indicates that the vermifilter effluents contain sufficient nutrients and can be used for application on crops or on soil.

3.4 AGP Test with BDL Effluent Diluted with Basal Medium

The results of experiments carried out with BDL dilutions fortified with 30% and 100% basal medium nutrients are shown in Tables 8 and 9. The control and 10% and 20% dilutions of BDL with 30% basal medium nutrients showed 48 hours lag phase, while there was no lag phase in other test cultures in both the effluents. This may be due to rich availability of nutrients in the test cultures. Exponential growth period was the same in all test cultures. In BDL dilutions with 30% basal medium nutrients, exponential growth rate was increasing upto 80% dilution; doubling time was minimum in 40% effluent, and maximum enhancement of standing crop on 7th day was in 40% dilution. This indicate that 30% nutrient fortification was favourable for enhancing the algal growth till 40% dilution of effluent, but in 60% to 100% effluent dilution, nutrient fortification might have resulted in excess nutrients and showed reduction in growth potential. In other words, BDL effluent had enough nutrient content and do not require nutrient fortification, except for dilutions from 10% to 40%. Fortification of BDL dilutions with 100% basal medium nutrients (Tables 9) showed that enhancement of standing crop was very less with relatively lower exponential growth rate and relatively higher doubling time. This indicates excess enrichment of test cultures due to fortification of nutrients. These observations show that the fortification of nutrients to the BDL effluent did not enhance the algal growth significantly.

3.5 AGP Test with BDH Effluent Diluted with Basal Medium

Similar observations were recorded in case of BDH effluent. In case of 30% nutrient fortification, standing crop showed enhancement in 10% to 60% dilution, concomitant with gradual reduction in doubling time and increase in exponential growth rate (Table 10). In case of fortification of 100% nutrients, exponential growth period was reduced to 6 days, Standing crop showed reduction upto 40% dilution and then slight enhancement; reduction in exponential growth rate upto 40% dilution then slight increase; and increase in doubling time upto 40% dilution and then slight decrease (Table 11). This indicates that BDH is rich in nutrients at optimum level and do not require nutrient fortification except at 40% dilution and that is upto 30% nutrients only.

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3.6 AGP Test with HPL and HPH Effluent Serially Diluted with Distilled Water

The results of the AGP test carried out with different dilutions of HPL and HPH effluents with distilled water are given in Tables 12 and 13. It has been observed that there was no lag phase in any of the test cultures. In both the effluents, the growth potential of alga showed significant improvement in exponential growth rate, decrease in doubling time and enhancement of standing crop over control with the increase in concentration of effluent in dilutions. Exponential growth period showed reduction with increase in concentration of effluent in dilution. This was due to faster nutrient utilization in shorter period in batch cultures. The 80% and 100% HPH effluent showed maximum enhancement of algal growth.

The above discussions lead to following salient observations.

- Vermitreated effluent of herbal pharmaceutical wastewater contains nutrients and growth promoting factors which significantly enhances the algal growth.
- The growth potential was better in HPL effluent as compared to that in HPH effluent. This may be due to better stabilization of waste organic matter under low organic loading resulting in slightly higher concentration of available nutrients in HPL effluent.

3.7 AGP Test with HPL Effluent Diluted with 30% and 100% Basal Medium Nutrients

The results of the AGP test with serial dilutions of HPL effluent fortified with 30% and 100% basal medium nutrients are shown in Tables 14 and 15. In both sets, the standing crop showed enhancement upto 60% dilution with concomitant increase in exponential growth rate and reduction in doubling time. However, there is reduction in standing crop and exponential growth rate, and increase in doubling time at 80% to 100% dilution. On the contrary, 100% nutrient fortification significantly increased the standing crop upto 80% dilution concomitant with increase in exponential growth rate and reduction in doubling time and then showed slight reduction, however better than control,. These observations show that HPL effluent might have sub-optimum concentration of available nutrients and growth promoting factors, thus showed improvement in algal growth potential significantly at 30% nutrient fortification and still more at 100% nutrient fortification.

3.8 AGP Test with HPH Effluent Diluted with 30% and 100% Basal Medium Nutrients

The results of the AGP test with serial dilutions of HPL effluent fortified with 30% and 100% basal medium nutrients are shown in Tables 16 and 17. Exponential growth period was of 7 days in 30% nutrient fortification and 6 days in 100% nutrient fortification. This was due to faster algal growth in a short time in the later. Algal growth potentials were tremendously increased in both the fortifications, higher in 100% fortification. However, highest algal growth potential was in case of 40% dilution in 30% nutrient fortification and in case of 60% dilution in 100% nutrient fortification. Comparison of algal growth potentials in HPL and HPH showed that HPL is more enriched with available nutrients and growth factors and thus showed less enhancement in standing crop after nutrient fortification over the control, while HPH being less enriched, showed significant enhancement in standing crop after nutrient fortification over the control.

IV. CONCLUSION

Bulk drug and herbal pharmaceutical wastewater were observed to be highly organically polluted wastewater having high suspended solids, total dissolved solids, COD and BOD_5 and dark yellow colour. Vermifilters were observed to be technically simple, low cost, efficient method for the treatment of high organically polluted wastewaters of pharmaceutical industry. The BOD_5:COD ratio of the vermitreated effluents ranging from 0.38 to 0.52 and COD:BOD_5 ratio ranging from 1.92 to 2.65 indicate that the effluents were not toxic in nature. Effluents from low organic loading (0.8 kg COD/m^3.d) treatment units were found to comply with Indian irrigation water standard (IS:2490-1982), while effluents from high organic loading (3.2 kg COD/m^3.d) treatment units may require further treatment to reduce their dissolved solids content, BOD_5 and iron content.

The biological characteristics of effluents were studied through AGP test. No residual toxicity was observed. AGP test showed that the vermitreated bulk drug and herbal pharmaceutical effluents were enriched with nutrients and growth promoting factors due to their treatment by the earthworm species *Eudrilus eugeniae*. Low organic loading (0.8 kg COD/m^3.d) treatment units produced effluent with better amount of available nutrients, while at higher organic loading (3.2 kg COD/m3.d) units, the effluents might contain some amount of partially stabilised organic matter and thus may require dilution for favourable effect on plant growth. Vermitreated bulk drug effluents contained more than optimum level of nutrients and 40% to 60% dilutions gave maximum beneficial impact on plant growth. HPL and HPH required fortification of nutrients for increasing its growth stimulatory effects. It is recommended that field trials on the crops may be carried out by using these vermitreated effluents from low organic loading treatment units either in spray form or as liquid manure or as irrigation water.

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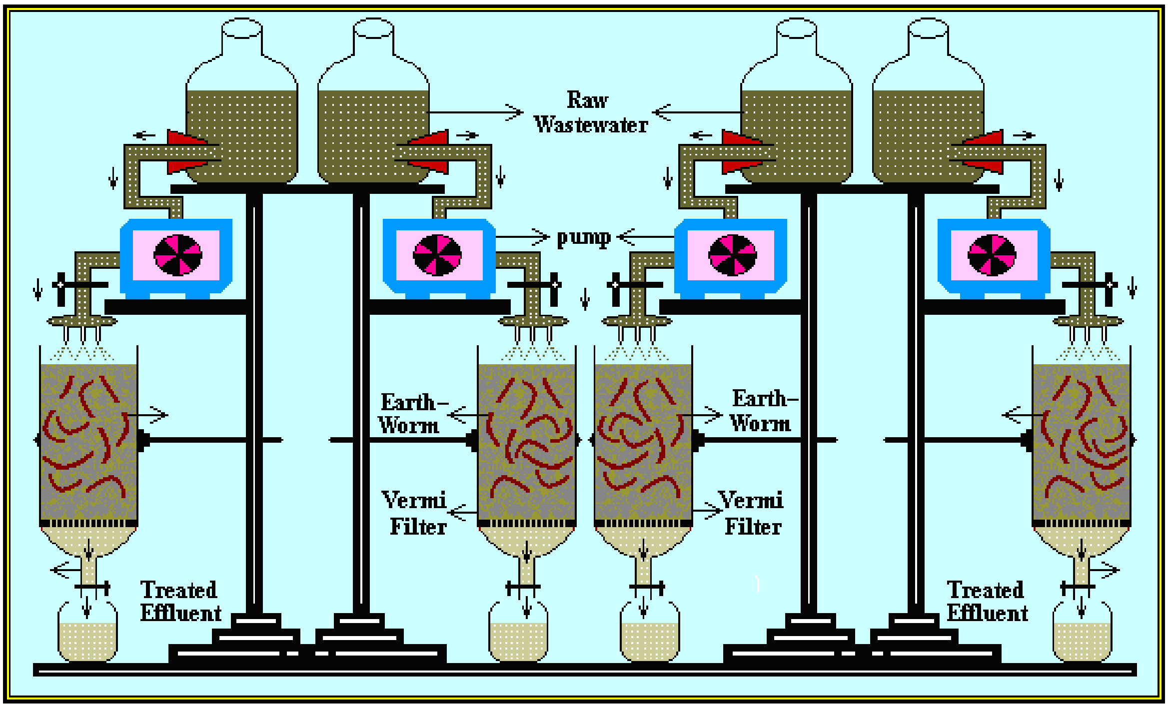

Figure 1: Experimental setup (Flow adjustment unit)

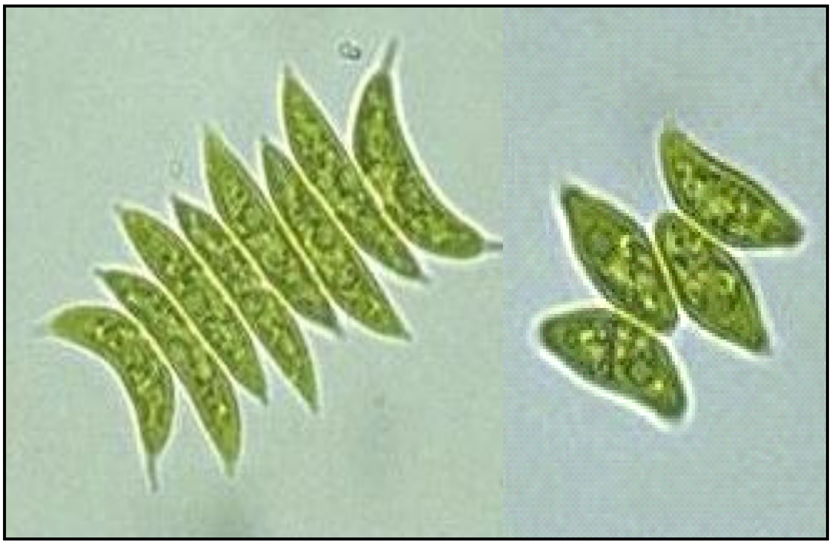

Figure 2**:** *Scenedesmus bijugatus* species

Table 1: The Nutrient Composition of Basal Medium for Culturing Alga S. Bijugatus

S.N.	Nutrient Salts	Concentration
1.	Urea	60 mg/l
2.	N_2CO_3	25 mg/l
3.	Na_3PO_4	25 mg/l
4.	NaCl	25 mg/l
5.	$(NH_4)_2SO_4$	20 mg/l
6.	$MgSO_4$	10 mg/l
7.	$FeSO_4$	2 mg/l

Table 2**:** Physico-Chemical Characteristics of Combined Herbal and Bulk Drug Pharmaceutical Wastewaters

Sr. No.	Parameters		HPW wastewater	BDP wastewater
1	pH		3.9 – 4.0	7.5
2	Colour (Visual)		Dark yellow	Dark yellow
3	Total acidity/ alkalinity as $CaCO_3$		3000	6200
4	Turbidity		64.4	58.8
5	Suspended solids (SS)		5460 – 7370	6100
6	Total dissolved solids (TDS)		2564 – 3660	25.934
7	Total solids		8024 – 11030	
8	Chemical oxygen demand (COD)		21960 – 26000	34800
9	Biochemical oxygen demand (BOD_5)		11200 – 15660	16000
10	Chloride		660-638	4193.69
11	Sulfide as S^-		42 – 54	330
12	Sulphates as SO_4		82 – 88	325
13	Total phosphates as PO_4		260 – 280	7.144
14	Total nitrogen as NH_3-N		389 – 498	370
15	Oil and grease		140 – 182	-
16	Sodium as Na		155 – 266	7197
17	Potassium as K		128 – 140	1120
18	Heavy metals			
	–	Zn	0.314	0.00
	–	Pb	0.434	0.525
	–	Cd	0.185	0.298
	–	Ni	0.156	0.178
	–	Co	0.16	0.048
	–	Mn	4.54	3.256
	–	Fe	33.8	9.189
	–	Cr	0.253	0.187
	–	Cu	0.042	0.01
	–	As	0.0062	-

All values are expressed in mg/l except pH and colour
HPW: Herbal Pharmaceutical Wastewater; BDP: Bulk drug Pharmaceutical Wastewater

Table 3: Effluent Characteristics with Respect to Ratios of BOD_5 and COD

Effluent parameters	HPL	HPH	BDL	BDH
COD	69	703	126	1097
BOD_5	26	367	60	563
BOD_5:COD	0.38	0.52	0.48	0.51
COD:BOD_5	2.65	1.92	2.1	1.95

Table 4: Compliance of Pharmaceutical Effluents to Indian Irrigation Water Standard

Parameters	Indian irrigation water standard (IS:2490 – 1982)	Pharmaceutical effluent from low organic loading (0.8 kg COD/m^3.d)	Excess parameters of pharmaceutical effluent from high organic loading (3.2 kg COD/m^3.d)
Suspended solids, mg/l	200	19 - 177	--
Dissolved solids (inorganic), mg/l, max.	2100	190 - 827	3706 (BDH)
pH	5.5 – 9.0	7.8 – 8.2	--
BOD_5, mg/l, max.	100	26 - 60	367 - 563
Chlorides (as Cl), mg/l, max.	600	39 - 226	--
Sulphate (as SO4), mg/l, max	1000	25-110	--
Manganese (as Mn), mg/l	2	0.022 – 0.136	--
Iron (as Fe), mg/l	3	2.1 – 3.21	6.55 (BDH)
Nitrate nitrogen, mg/l	20	Total nitrogen: 1.36 – 1.82	--

Table 5: Physico-Chemical Characteristics of Effluents of Herbal and Bulk Drug Pharmaceutical Wastewater at 2 Days HRT

Sr. No.	**Parameter**	**Organic loading rate (kg COD/m^{3}d)**			
		0.8 (HPL)	**3.2 (HPH)**	**0.8 (BDL)**	**3.2 (BDH)**
1	pH	8.2	7.8	8.2	7.8
2	Alkalinity as $CaCO_3$	373	466	284	340
3	Turbidity (NTU)	0.88	1.82	4.6	9.0
4	Total suspended solids (TSS)	22.0	177.0	19	127
5	%TSS reduction	91.6	83.1	93.6	89.0
6	Total dissolve solids (TDS)	190	809	827	3706
7	%TDS reduction	35.8	26.6	32.2	24.08
8	Chemical oxygen demand (COD)	69	703	126	1097
9	%COD reduction	94.48	85.44	92.34	83.34
10	Biochemical oxygen demand (BOD_5)	26	367	60	563
11	%BOD_5 reduction	96.26	89.77	93.92	85.73
12	Chloride as Cl	39	86	224	256
13	Sulphide as S^-	ND	ND	ND	ND
14	Sulphate as SO_4	25	34	94	110
15	Total phosphate as PO_4 (%)	0.26	0.82	0.25	0.40
16	Total nitrogen as NH_3-N (%)	1.40	1.82	1.36	1.60
17	Sodium as Na	85.5	168	146	284
18	Potassium as K	0.29	0.49	0.29	0.69
19	Sodium adsorption ratio (SAR)	3.95	4.76	4.16	5.03
20	Heavy Metals				
	– Zn	0.126	0.156	0.086	0.097
	– Pb	0.098	0.142	0.26	0.392
	– Cd	0.016	0.31	0.192	0.232
	– Ni	0.033	0.049	0.106	0.143
	– Co	0.015	0.041	0.028	0.042
	– Mn	0.712	0.091	1.02	1.32
	– Fe	2.1	3.21	2.35	6.55
	– Cr	0.022	0.036	0.112	0.136
	– Cu	ND	0.016	0.004	0.009

*Above readings are averages of ten sets

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

Table 6: Growth of S. Bijugatus at Different Dilutions of BDL Effluent

Treated effluent dilutions	**Lag phase (days)**	**Exponential growth period day**	**Exponential growth rate (µ)**	**Doubling time in hours**	**Enhancement of standing crop on 7th Day (%)**
Control (Basal medium)	Nil	0 – 7	0.2486	96.54	-
10%	Nil	0 – 7	0.3186	75.32	40
20%	Nil	0 – 7	0.3386	70.88	55
40%	Nil	0 – 7	0.3557	43.09	68
60%	Nil	0 – 7	0.2957	81.16	26
80%	Nil	0 – 7	0.2857	84.00	20
100%	Nil	0 – 7	0.2771	86.61	15

Table 7: Growth of S. Bijugatus in Different Dilutions of BDH Effluent

Treated effluent dilutions	Lag phase (days)	Exponential growth period days	Exponential growth rate (µ)	Doubling time in hours	Enhancement of standing crop on 7th day (%)
Control (Basal medium)	Nil	0 – 7	0.2057	116.7	-
10%	Nil	0 – 7	0.2529	94.9	26.3
20%	Nil	0 – 7	0.2814	85.3	45.3
40%	Nil	0 – 7	0.3271	73.4	81.1
60%	Nil	0 – 7	0.3314	72.4	84.2
80%	Nil	0 – 7	0.2971	80.8	55.8
100%	Nil	0 – 7	0.2914	82.4	51.6

Table 8: Growth of S. Bijugatus in Different Dilutions of BDL Effluent Fortified with 30% Basal Medium Nutrients

Treated effluent dilutions	Lag phase (hrs)	Exponential growth period	Exponential growth rate (µ)	Doubling time in hours	Enhancement of standing crop as on 7th Day (%)
Control (Basal Medium)	48 hrs.	0 –7	0.3643	65.9	-
10%	48 hrs.	0 – 7	0.3586	66.9	- 3.13
20%	48 hrs.	0 –7	0.4071	59.0	23.2
40%	Nil	0 –7	0.4429	54.2	46.4
60%	Nil	0 – 7	0.3871	62.0	11.6
80%	Nil	0 – 7	0.4257	56.4	34.8
100%	Nil	0 – 7	0.3529	68.0	-5.36

Table 9: Growth of S. Bijugatus in Different Dilutions of BDL Effluent Fortified with 100% Basal Medium Nutrients

Treated effluent dilutions	Lag phase (days)	Exponential growth period days	Exponential growth rate (µ)	Doubling time in hours	Enhancement of standing crop as on 7th day (%)
Control (Basal medium)	Nil	0-7	0.3557	67.5	-
10%	Nil	0-7	0.3586	66.9	0.27%
20%	Nil	0-7	0.3743	64.1	1.70%
40%	Nil	0-7	0.38	63.2	2.30%
60%	Nil	0-7	0.42	57.1	6%
80%	Nil	0-7	0.4586	52.32	9.70%
100%	Nil	0-7	0.4714	50.9	10.90%

Table 10: Growth of S. Bijugatus in Different Dilutions of BDH Effluent Fortified with 30% Basal Medium Nutrients

Treated effluent dilutions	Lag phase (days)	Exponential growth period days	Exponential growth rate (µ)	Doubling time in hours	Enhancement of standing crop as on 7th day (%)
Control (Basal medium)	Nil	0-7	0.3429	70	-
10%	Nil	0-7	0.42	57.1	45.50%
20%	Nil	0-7	0.4357	55.1	63.80%
40%	Nil	0-7	0.4514	53.2	69.40%
60%	Nil	0-7	0.49	49	105%
80%	Nil	0-7	0.4629	51.9	80.20%
100%	Nil	0-7	0.4443	54	64.50%

Table 11: Growth of S. Bijugatus in Different Dilutions of BDH Effluent Fortified with 100% Basal Medium Nutrients

Treated effluent dilutions	**Lag phase**	**Exponential growth period days**	**Exponential growth rate (µ)**	**Doubling time in hours**	**Enhancement of Standing crops as on 7th day (%)**
Control (Basal medium)	Nil	0-6	0.3657	65.63	-
10%	Nil	0-6	0.3414	70.3	-2.27%
20%	Nil	0-6	0.3586	66.93	-0.67%
40%	Nil	0-6	0.3558	67.45	-0.93%
60%	Nil	0-6	0.39	61.54	2%
80%	Nil	0-6	0.4543	52.83	8.27%
100%	Nil	0-6	0.4614	52.02	8.93%

Table 12: Growth Potential of S. Bijugatus in Different Dilutions of HPL Effluent

Treated effluent dilutions	**Lag phase (days)**	**Exponential growth period days**	**Exponential growth rate (µ)**	**Doubling time in hours**	**Enhancement of standing crop over control as on 7th day (%)**
Control (Basal medium)	Nil	0-7	0.3357	71.5	-
10%	Nil	0-7	0.3429	69.9	3.9
20%	Nil	0-7	0.38	63.2	24.5
40%	Nil	0-5	0.56	42.9	43.1
60%	Nil	0-5	0.57	42.1	52.9
80%	Nil	0-5	0.614	39.1	82.4
100%	Nil	0-5	0.604	39.7	61.8

Table 13: Growth Potential of S. Bijugatus in Different Dilutions of HPH Effluent

Treated effluent dilutions	**Lag phase (days)**	**Exponential growth period days**	**Exponential growth rate (µ)**	**Doubling time in hours**	**Enhancement of standing crops as on 7th day (%)**
Control	Nil	0-7	0.2629	91.3	-
10%	Nil	0-4	0.47	51.1	0.9
20%	Nil	0-4	0.455	52.7	9.3
40%	Nil	0-5	0.42	57.1	23.4
60%	Nil	0-5	0.44	54.5	36.4
80%	Nil	0-5	0.502	47.8	62.6
100%	Nil	0-5	0.52	46.2	69.2

Table 14: Growth of S. Bijugatus in Different Dilutions of HPL Effluent Fortified with 30% Basal Medium Nutrients

Treated effluent dilutions	**Lag phase (days)**	**Exponential growth period days**	**Exponential growth rate (µ)**	**Doubling time in hours**	**Enhancement of standing crops as on 7th day (%)**
Control (Basal medium)	Nil	0-7	0.4457	53.8	-
10%	Nil	0-7	0.4514	53.2	7.8
20%	Nil	0-7	0.4829	49.7	19.3
40%	Nil	0-7	0.7214	33.3	29.8
60%	Nil	0-7	0.75	30.1	35.8
80%	Nil	0-7	0.4429	54.2	- 1.4
100%	Nil	0-7	0.3443	69.7	- 39.0

Table 15: Growth of S. Bijugatus in Different Dilutions of HPL Effluent Fortified with 100% Basal Medium Nutrients

Treated effluent dilutions	**Lag phase (days)**	**Exponential growth period days**	**Exponential growth rate (µ)**	**Doubling time in hours**	**Enhancement of standing crop as on 7th day (%)**
Control (Basal medium)	Nil	0 – 6	0.27	88.89	-
10%	Nil	0 – 6	0.3017	79.55	13.82
20%	Nil	0 – 6	0.4067	59.01	76.42
40%	Nil	0 – 6	0.465	51.61	125.20
60%	Nil	0 – 6	0.5333	45.00	200
80%	Nil	0 – 6	0.5283	45.43	192.68
100%	Nil	0 – 6	0.4417	54.34	104.07

Table 16: Growth of S. Bijugatus in Different Dilutions of HPH Effluent Fortified with 30% Basal Medium Nutrients

Treated effluent dilutions	**Lag phase (days)**	**Exponential growth period days**	**Exponential growth rate (µ)**	**Doubling time in hours**	**Enhancement of standing crop as on 7th day (%)**
Control (basal medium)	Nil	0-7	0.3671	65.38	-
10%	Nil	0-7	0.5042	47.52	94.01
20%	Nil	0-7	0.5071	47.33	97.60
40%	Nil	0-7	0.52	46.15	109.58
60%	Nil	0-7	0.4743	50.60	68.26
80%	Nil	0-7	0.4657	51.54	61.68
100%	Nil	0-7	0.3857	62.22	9.58

Table 17: Growth of S. Bijugatus in Different Dilutions of HPH Effluent Fortified with 100% Basal Medium Nutrients

Treated effluent dilutions	**Lag phase**	**Exponential growth period days**	**Exponential growth rate (µ)**	**Doubling time in hours**	**Enhancement of standing crop as on 7th day (%)**
Control (basal medium)	Nil	0 – 6	0.1617	148.4	-
10%	Nil	0 – 6	0.385	62.3	138.3
20%	Nil	0 – 6	0.4717	5.1	240.4
40%	Nil	0 – 6	0.5083	47.2	296.8
60%	Nil	0 – 6	0.5433	44.1	358.5
80%	Nil	0 – 6	0.4967	48.3	277.7
100%	Nil	0 – 6	0.3517	68.2	106.4