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Large scale phycoremediation of oil drilling effluent

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Abstract

Oil drilling effluent treatment plant at Kakinada, Andhrapradesh, India, was selected for investigation. 18 genera and 23 species belonging to Chlorophyceae, 5 genera and 6 species belonging to Bacillariophyceae, 2 genera and 3 species belonging to Euglenineae and 13 genera and 17 species belonging to Myxophyceae were identified from the ETP site at Kakinada. On the whole 38 genera and 49 species belonging to 4 families were identified. Based on the laboratory feasibility studies a few micro algae were selected for trials in the field. Significant reduction in BOD, COD, Chromium and copper was observed in the lab trials. Chlorococcum humicola adapted to pilot slope tank conditions and grew very well. The effluent was loaded continuously using a calibrated regulator mechanism. The chemical parameters like sulphate was reduced by 95.81%, BOD got reduced by 70.27% and total alkalinity by 70.51%. Scaled up slope tank was built to remediate and evaporate the effluent. Sludge was reduced by 47.75%. BOD was reduced by 93.20%, total suspended solids by 80.83%, TDS by 80.79% and EC by 80.83%. pH of effluent increased and maintained around 7.78 against raw effluent pH of 6.45. In a comparative analysis of oil drilling effluent both in the lab and in field, many parameters showed considerable reduction in field trial when compared to that of lab level study.

Keywords: Phycoremediation, oil drilling waste, *Chlorococcum humicola*

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Introduction

Olguin (2003) defines phycoremediation involves the use of macro algae or microalgae for effective removal or biotransformation of pollutants, including nutrients and xenobiotics from wastewater and CO_2 from waste air. Large-scale phycoremediation of industrial effluent is being implemented successfully in a number of industries in India (Sivasubramanian, 2006; Sivasubramanian *et al.,* 2009; Sivasubramanian, 2010; Sivasubramanian *et al.,* 2010; Hanumantha Rao *et al.,* 2010). Using algae based treatment technology efficient pH correction, sludge reduction and reduction of BOD and COD could be achieved by avoiding toxic chemicals by these industries. One of the major applications of algae based remediation is the rapid removal of nutrients from industrial effluents (Sivasubramanian, 2011). There are a number of industries in India providing total solutions in waste chain management for off shore & Onshore Oil & Gas Operators with a focus on reduction of waste, recycling and recovery/reuse of valuable base-oil & oil based mud with the prime motto of converting waste to value.

Present practices in India allow for easier disposal of water based mud with restrictions on use of Synthetic Oil Based Mud (SOBM). The offshore disposal of wastes is allowed with limitation on discharges. The regulations in India are becoming more and more stringent and Ministry of Environment Forest (MoEF) is insisting on cleaner/better disposal practices of drilling wastes and these are expected to become mandatory in the near future. The skips are transported to the treatment facility and the slops transferred to a storage tank for treatment. The composition of slop is normally in the range of 90% water, 8-9% oil and 1-2% solids. Slop is allowed to settle for some time to facilitate natural separation of oil, water and sediment phases. The next step is to reduce the amount of water from the liquid phase. This process is done in a mixing tank. Proprietary chemicals – emulsion breakers – are added to break the emulsion between base oil and water. These emulsion breakers disturb the surface tension of the emulsified water, with the result that free water can be separated.

There are two phases in the mixing tank after adding emulsion breakers, one water phase and one SOBM fluid phase. The water phase is transferred to a storage tank for further polishing, and the SOBM phase can be re-used. The final polishing of the water phase is done by flocculation/filtration. The clean water can be re-used as washing water, or discharged into "the green belt".The tank cleaning for Brine tanks etc is also carried out as per the requirements of the client but this waste is sent to Hazardous waste TSDF for disposal as per the regulatory norms.

Drill Cuttings/drilling waste Process:

Drill Cuttings / drilling waste contaminated with Oil-Based Mud / Synthetic-Oil Based Mud (OBM/SOBM) during drilling are collected in sealed skips and transported from the base / quay-side to the SAR-Chandra facility. Cuttings are fed to cuttings drier where the coarse solids and liquid phases are separated by the G-force. The dry cuttings are collected for disposal. The liquid phase is taken to a decanter-centrifuge for removal of fine particles. The fine fraction is separately collected for disposal. Coarse and fine particles collected are further processed in APEX facility for further recovery of Base oil & fluid and make the solids suitable for disposal as per the disposal norms. The fluid recovered from the decanter is pumped into Slop treatment described above. Treated Waste to Disposal Site: The treated drill cuttings / drilling waste which are devoid of oil to the extent of less than 10 gm per Kg of drill cuttings are stored and sent for safe disposal in a treated drill cuttings disposal pit as per Regulatory requirements. The trucks carrying the treated drilling Waste will unload the waste in a safe disposal facility / lined pit. The facility is designed on the premise that it is exclusively used for disposal of Treated drilling waste from Oil & Gas Industry which is provided with HDPE Liner and Leachate Collection System. The treated drilling waste will have oil below 10 gm/kg and no other toxic elements thus meeting the MoEF guidelines for disposal in to lined pit. The Oil drilling industrial effluents has higher inorganic chemicals from oil separation process which utilizes HCl, Triton X, sodium bicarbonate etc. This effluent is alkaline and high in TDS.

The present study deals with finding a viable treatment solution for oil drilling effluent using micro algae at the pilot as well as largescale. The investigation was conducted in three phases I. Lab trials II Pilot trials and III Scaled up

Materials and methods

The effluent collected periodically from the factory premises was subjected to laboratory examination and the micro algae were isolated from the effluent using serial dilution, standard plating, colony isolation and culture techniques. The microalgae were identified following the monograph of Desikachary (1959), Philipose (1967), Fritsch (1935), Krishnamurthy (1954, 2000), Venkataraman (1939), West et al., (1923), Anand (1998), Prescott(1951) and Prasad and Misra (1992). Effluent parameters were analyzed by employing APHA Standard methods (2000). Growth was measured by counting cells using haemocytometer and using the formula:

$$\frac{\log N - \log N_0}{\log 2 \; x t}$$

Laboratory growth conditions

The cultures were grown at 24 ± 1°C in a thermo-statically controlled environmental chamber illuminated with cool white fluorescent lamps (Philips 40w, cool daylight, 6500k) at an intensity of 2000 LUX in a 12/12 h light/dark cycle. Bold basal medium was used for maintaining micro algae (Nichols and Bold, 1965)

Results and Discussion

Occurrence of algae in Oil drilling ETP Waste and Effluents - Kakinada, Andhrapradesh

Algae occurred in and around oil drilling ETP facility, Kakinada, Andhrapradesh, were isolated and identified.

Some of the algae were cultured in the lab. 18 genera and 23 species belonging to Chlorophyceae, 5 genera and 6 species belonging to Bacillariophyceae, 2 genera and 3 species belonging to Euglenineae and 13 genera and 17 species belonging to Myxophyceae were identified. On the whole 38 genera and 49 species belonging to 4 families were identified during November 2008.

List of microalgae identified in Oil drilling industrial ETP site:

Chlorophyceae

Ankistrodesmus convolutus Corda
Chlamydomonas pertusa Chod.v.*indica*.Iyengar.
Chlorella vulgaris Beijerinck
Chlorococcum humicola (Naegeli) Rabenhorst
Coelastrum cambricum Archer
Closterium decorum Breb.
Cosmarium undulatum Corde ex Ralfs.
Crucigenia tetrapedia (Kirchner) W.et G.S. West.
Desmococcus olivaceus (Persoon et Acharius) J.R. Laundon
Eudorina elegans Ehrenb.
Kirchneriella lunaris (Kirchn.) Moebius
Pandorina morum Bory.
Scenedesmus quadricauda (Turp.) Breb. var. *quadrispina* Chodat.
Scenedesmus bijugatus (Turp.) Kuetz.
Scenedesmus obliquus (Turp) Kuetz.
Scenedesmus opoliensis Richter
Selenastrum minutum (Naegeli) Collins.
Staurastrum coroniferum WB Turner.
Staurastrum pinnatum Turner
Tetraedron muticum (A.Braun) Hansgirg
Tetraedron enorme var. *pentaedricum* Prescott.
Oocystis elliptica W. West
Ulothrix elongatum Hodgetts

Bacillariophyceae

Cymbella affinis Kuetz.
Fragilaria virescens Ralfs.
Navicula viridula (Kuetz.) Ehr.
Navicula pupula Kuetz.
Nitzschia stagnorum Rabenh.
Pleurosigma javanicum Grun.

Euglenineae

Euglena acus Ehrenb.
Euglena polymorpha Dang.
Phacus longicauda (Ehrenb.) Dujardin

Myxophyceae

Anabaena circinalis Rabenh.
Aphanocapsa biformis A. Braun.
Calothrix marchica Lemmermann
Chroococcus turgidus v.*maximus* Nygaard
Gloeotrichia intermedia v. *kanwaensis* C.B. Rao.
Merismopedia aeruginea Breb.
Microcystis robusta Nygaard.
Nostoc calcicola Breb.
Oscillatoria proboscidea Gomont.
Oscillatoria curviceps Ag. ex Gomont.
Oscillatoria salina Biswas
Oscillatoria subbrevis Schmidle
Oscillatoria terebriformis Ag.
Phormidium tenue (Menegh.) Gomont
Scytonema bohneri Schmidle
Spirulina gigantea Schmidle
Synechocystis aquatilis Sauv.

Growth of various micro algae in Oil drilling industrial effluent

Adaptability of algae to the effluent was studied by studied under laboratory conditions by employing individual algae, such as, *Chlamydomonas pertusa, Chlorella vulgaris, Chlorococcum humicola, Chlorococcum vitiosum, Chroococcus turgidus, Dactylococcopsis raphioides, Desmococcus olivaceus, Scenedesmus dimorphus* and *Scenedesmus incrassatulus*. For the study, 20 ml of the effluent was taken in 50 ml test tube with 2ml of the algae was inoculated. After one week of incubation, growth rates were determined and tabulated (Table 1). *Chlorococcum humicola* showed the maximum growth rate of 0.2471 divisions/day followed by *Chlorococcum vitiosum, Chlamydomonas pertusa, Desmococcus olivaceus, Chlorella vulgaris* and *Dactylococcopsis raphioides* which showed a growth rate of 0.2252, 0.1141, 0.0759, 0.0667 and 0.0230 divisions/day respectively. *Chroococcus turgidus, Scenedesmus dimorphus* and *Scenedesmus incrassatulus* showed a very poor growth.

Table 1 Growth rate of various micro algae in Oil drilling industrial effluent (Kakinada)

S.No	Micro algae	Growth rate (Divisions/day)
1	*Chlamydomonas pertusa*	0.1141
2	*Chlorella vulgaris*	0.0667
3	*Chlorococcum humicola*	0.2471
4	*Chlorococcum vitiosm*	0.2252
5	*Chroococcus turgidus*	0.0000
6	*Dactylococcopsis raphioides*	0.0230
7	*Desmococcus olivaceus*	0.0759
8	*Scenedesmus dimorphus*	0.0000
9	*Scenedesmus incrassatulus*	0.0000

Experiment was also conducted by addition of BBM and CFTRI nutrients to the effluent and treated with micro algae, *Chlorococcum humicola, Chlorococcum vitiosum* and *Chlamydomonas pertusa.* Growth rates were tabulated Table 2. *Chlorococcum humicola* showed maximum growth rate of 0.4060 divisions/day when amended with BBM nutrients and *Chlamydomonas pertusa* showed maximum growth rate of 0.5669 divisions/day, when amended with CFTRI nutrients.

Table 2 Growth of various micro algae in Oil drilling industrial effluent (Kakinada) amended with BBM and CFTRI nutrients

S.no	Micro algae	Growth rate (Divisions/day)	
		BBM	CFTRI
1	*Chlamydomonas pertusa*	0.2457	0.5669
3	*Chlorococcum humicola*	0.4060	0.5084
4	*Chlorococcum vitiosm*	0.2820	0.5264

Growth of micro algae and pH in Oil drilling industrial effluent (Periodic addition)

Chlorococcum humicola, Chlamydomonas pertusa, Chlorococcum vitiosum and equal mixture of these algae were used for the Oil drilling industrial waste effluent treatment. 100ml of actively grown algae was taken individually and in mixture. Everyday 10ml of the culture media alone was replaced by 10ml of oil drilling industrial effluent. The pH of the effluent was monitored periodically for 10 days and growth rate was also tabulated. There was an increase in pH when compared to control for all algae. Algal mixture responded well than individual algae. *Chlorococcum humicola* showed slight increase in pH than other algae. *Chlorococcum humicola* showed maximum growth rate of 0.1407 divisions/day, followed by *Chlorococcum vitiosum* and *Chlamydomonas pertusa* which showed growth rate of 0.1223 and 0.1199 divisions/day respectively. In mixed algae trial *Chlorococcum humicola* exhibited maximum growth 0.2090 divisions/day followed by other micro algae. *Chlorococcum humicola,* showed maximum pH of 8.84 followed by mixed algae, *Chlorococcum vitiosum* and *Chlamydomonas pertusa* which showed pH of 8.57, 8.54 and 8.53 respectively against control. The results are given in the Tables 3 and 4.

Table 3 Growth of various algae in Oil drilling industrial effluent (Kakinada) under lab conditions

S.no	Micro algae	Growth rate (division/day)
1	*Chlorococcum humicola*	0.1407
2	*Chlamydomonas pertusa*	0.1199
3	*Chlorococcum vitiosm*	0.1223
4	**Mixed algae**	0.1459
	Chlorococcum humicola	0.2090
	Chlamydomonas pertusa	0.0568
	Chlorococcum vitiosm	0.1326

Table 4 pH variations of various algae in Oil drilling industrial effluent (Kakinada) under lab conditions

S.no	Micro algae	pH monitored on different days									
		1	2	3	4	5	6	7	8	9	10
1	Control	7.41	7.47	7.69	7.97	8.09	8.08	7.89	7.90	7.72	8.03
2	*Chlorococcum humicola*	9.82	8.85	9.41	8.69	8.78	8.32	8.45	8.26	7.89	8.84
3	*Chlamydomonas pertusa*	8.93	7.63	9.29	8.31	8.31	9.09	8.04	8.12	7.59	8.53
4	*Chlorococcum vitiosm*	9.13	7.57	9.06	8.13	8.44	8.88	7.98	8.09	7.58	8.54
5	Mixed Algae	9.09	8.20	9.35	8.17	8.54	8.97	7.97	8.09	7.65	8.57

Phycoremediation of Oil drilling industrial effluent treated with micro alga: (In Lab)

Based on the feasibility study of Oil drilling industrial effluent *Chlorococcum humicola* which showed maximum growth under laboratory conditions was selected for further study. Two L of effluent were taken in two 3L conical flask separately. One served as control and another containing a mixture of *Chlorococcum humicola*, *Chlorococcum vitiosum* and *Chlamydomonas pertusa* in equal proportion. After 10 days growth and physico-chemical parameters were analyzed.

The results of the lab trials were encouraging. The total cell count reached 272 x 10^4 cells/ml, *Chlorococcum humicola* dominated. Parameters like total hardness, Ca, Mg, Na, K and chlorides showed significant reduction. There was also a reduction in TDS and total solids. BOD reduced drastically by 96.17% and COD by 52.19%. Chromium also reduced by 92.57% followed by copper (88.17%). There was also a 78.04% reduction in nitrate levels. The results are given in the Table 5

Table 5 Phycoremediation of in Oil drilling industrial effluent treated with micro alga: Laboratory trials

Parameters	Raw effluent	Effluent treated With alga	% reduction
PHYSICAL EXAMINATION			
Turbidity NTU	56.3	23.2	**32.55**
Total solids mg/L	16564	15316	**7.53**
Total Dissolved Solids (TDS) mg/L	16492	15262	**7.45**
Total suspended solids (TSS) mg/L	72	54	**25**
Electrical conductivity (micro mho/cm)	23488	21770	7.31
CHEMICAL EXAMINATION			
pH	6.45	7.20	-
Alkalinity pH (as Ca CO_3) mg/L	0	0	0
Alkalinity total (as Ca CO_3) mg/L	390	198	**49.23**
Total Hardness (as Ca CO_3) mg/L	375	975	-
Calcium (as Ca) mg/L	90	210	-
Magnesium (as Mg) mg/L	36	108	-
Sodium (as Na) mg/L	525	1725	-
Potassium (as K) mg/L	88	175	-
Iron (as Fe) mg/L	1.38	1.56	-
Manganese (as Mn) mg/L	nil	nil	Nil
Free ammonia (as NH_3) mg/L	2.24	3.24	-
Nitrite (as NO_2) mg/L	nil	0.22	-
Nitrate (as NO_3) mg/L	41	9	**78.04**
Chloride (as Cl) mg/L	351	1224	-
Sulphate (as SO_4) mg/L	215	200	6.97
Phosphate (as PO_4) mg/L	3.42	2.82	17.54
Tidy's test (as O) mg/L	445.2	43	**90.34**
Silica (as SiO_2) mg/L	13.53	32.47	-
BOD mg/L	4710	180	**96.17**
COD mg/L	1050	502	**52.19**
Total Kjeldhal Nitrogen mg/L	3.36	31.36	-
Copper (as Cu) mg/L	0.00812	0.00096	**88.17**
Zinc (as Zn) mg/L	0.147	0.090	**38.77**
Chromium (as Cr) mg/L	0.00485	0.00036	**92.57**

Phycoremediation of Oil drilling industrial effluent in pilot slope tank in Kakinada

To acclimatize the algae in that particular effluent, an experiment was carried out. *Chlorococcum humicola, Chlorococcum vitiosum and Chlamydomonas pertusa* showed a better growth in lab trials. So it was used for field level study by constructing a slope tank of length 193cm X width 193cm X height 90cm (46.5 L/cm) and inoculated with equal proportion of mixture of algae in 2 KL of improvised CFTRI medium in the HRA pond and allowed to reach the exponential phase. Effluent was added every day according to the evaporation rate so that the final volume remained unchanged. Agitation was provided by manual mixing using a paddle thrice a day. *Chlorococcum humicola* showed maximum growth among the three species and increased pH in field trials. After the phycoremediation process, the cell number, pH and TDS were monitored then the treated effluent was analyzed.

Effect of continuing addition of Oil drilling industrial effluent in pilot scale treatment using micro alga

To the rich *Chlorococcum humicola* algal culture developed in tank, tolerance to the effluent was determined by loading it with 100, 200, 300 and 600L/day with continuous flow rate. The cell number, pH and TDS were monitored. The observations showed that alga could effectively maintain pH between 7.16 and 7.54. The cell number also slightly increased in all levels of effluent loading rates.

Effluent was added periodically (100, 200, 300 and 600 L/day) with a continuous flow from 8.00 AM to 6.00 PM by drop by drop through out the day. The pH, TDS and cell number were noted regularly. Raw effluent had pH of 6.15 which showed slight increase in pH of 7.34 after treatment with alga. The results are given in the Table 8. After treatment the effluent showed a tremondous sludge reduction (69.4%).

Chlorococcum humicola was grown actively in pilot tank. When the cell count reached the maximum effluent was added. After 54 days of treatment (evaporation and addition of raw effluent) the cell count reached 278 x 10^4 cells/ml. Sample was drawn and analyzed for various physico-chemical parameters. In spite of evaporation and raw effluent addition (80 L/day) the parameters did not show corresponding increase in levels indicating efficient remediation and reduction in sludge.

Phycoremediation potential of *Chlorococcum humicola* in the pilot scale slope tank was studied. The pH increased to 7.48 against raw effluent pH of 6.45. The chemical parameters like sulphate reduced by 95.81%, BOD reduced by 70.27% and total alkalinity by 70.51%. At the same time there was considerable increase in chloride, sodium, potassium and total hardness. The results are given in the Tables 6 and 7. The sludge reduction achieved was 69.4%.

Table 6 Phycoremediation of Oil drilling industrial effluent treated with *Chlorococcum humicola* : Pilot slope tank

Parameters	Raw effluent	Effluent from pilot slope tank treated with alga	% reduction
PHYSICAL EXAMINATION			
Turbidity NTU	56.3	42.5	24.51
Total solids mg/L	16564	14544	**12.19**
Total Dissolved Solids (TDS) mg/L	16492	14410	**12.62**
Total suspended solids (TSS) mg/L	72	134	-
Electrical conductivity (micro mho/cm)	23488	20561	12.46
CHEMICAL EXAMINATION			
pH	6.45	7.48	-
Alkalinity pH (as Ca CO_3) mg/L	0	0	0
Alkalinity total (as Ca CO_3) mg/L	390	115	**70.51**
Total Hardness (as Ca CO_3) mg/L	375	5850	-
Calcium (as Ca) mg/L	90	1300	-
Magnesium (as Mg) mg/L	36	624	-
Sodium (as Na) mg/L	525	6900	-
Potassium (as K) mg/L	88	850	-
Iron (as Fe) mg/L	1.38	22.64	-
Manganese (as Mn) mg/L	nil	Nil	Nil

Free ammonia (as NH_3) mg/L	2.24	10.08	-
Nitrite (as NO_2) mg/L	nil	nil	Nil
Nitrate (as NO_3) mg/L	41	48	-
Chloride (as Cl) mg/L	351	6393	-
Sulphate (as SO_4) mg/L	215	9	**95.81**
Phosphate (as PO_4) mg/L	3.42	19.01	-
Tidy's test (as O) mg/L	445.2	328	26.32
Silica (as SiO_2) mg/L	13.53	49.38	-
BOD mg/L	4710	1400	**70.27**
COD mg/L	1050	3423	-
Total Kjeldhal Nitrogen mg/L	3.36	10.08	-
Copper (as Cu) mg/L	0.00812	0.0080	1.47
Zinc (as Zn) mg/L	0.147	0.143	2.72
Chromium (as Cr) mg/L	0.00485	0.00485	-

Table 7 Calculations for the sludge removal in pilot tank during algal treatment

Calculation for the sludge removal in pilot tank scale during the algal treatment

Average pH : 6.15

Average TDS : 21412 mg/L

From 11.11.08 onwards to 06.06.09, effluent added to pilot scale : 12610 Liters

Initial TDS : 820 mg/l X 2000 L = 1640000 mg

Added effluent TDS 21412 mg/l X 8630 L = 184785560 mg

Added fresh water 820 mg/l X 3480 L = 2853600 mg

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14110 L 189279160 mg

Final TDS : 28952 mg/l X 2000 L (-) = 57904000 mg (-)

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12110 L = 131375160 mg

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Sludge reduction = 131.375 kg / 12110 L Effluents

= 10.84 g / L

Sludge reduction = 69.40 %

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Table 8 Effect of Oil drilling industrial effluent (Kakinada) loading in a pilot scale treatment using micro alga

S.No	Effluent Added (L/day)	pH				TDS (mg/L)				Cell Count ($X10^4$cells/ml)
		Raw Effluent	Treated Effluent			Raw Effluent	Treated Effluent			Average
			8.30am	5.00pm	Average		8.30am	5.00pm	Average	
1.	100	5.98	7.10	7.22	7.16	20939	18894	18862	18878	267.5
2.	200	6.45	7.52	7.56	7.54	19856	16424	16906	16665	230
3.	300	6.13	7.20	7.40	7.30	24362	18640	18826	18733	267.5
4.	600	6.00	7.52	7.23	7.37	20492	18614	18462	18538	243.5
Average		**6.15**	**7.33**	**7.35**	**7.34**	**21412**	**18143**	**18264**	**18203**	**252.12**

Effect of algal treatment on Oil drilling industrial effluent in scaled up sloping tank, Kakinada

Scaling up was done by constructing large tank with a dimension of length 12 m X width 12 m X height 1.9 m (1440 L/cm) with a capacity of 44,000 L of effluent. Scaled up plant was started with 500 L of algal inoculum from pilot tank. The effluent was added to the tank gradually with adjusted flow (at the rate of 1.5 KL/day). The sample for analysis was drawn on 44^{th} day when the cell count reached 132 x 10^{4}/ml. The analytical data are given in the Tables 9 and 10. Results show a significant reduction in a number of parameters considering the fact that 1.5KL water has evaporated and replaced with raw effluent everyday. Sludge was reduced by 47.75%. BOD was reduced by 93.20%, total suspended solids by 80.83%, TDS by 80.79% and EC by 80.83%. pH of effluent increased and maintained around 7.78 against raw effluent pH of 6.45. In a comparative analysis of Oil drilling effluent both in the lab and in field, many parameters showed considerable reduction in field trial when compared to that of lab level study. There was a 80.83% (scaled up tank) and 12.19% (pilot tank) reduction of TS against 7.53% in the lab, 80.79% (scaled up tank) and 12.62% (pilot tank) of TDS against 7.45% in the lab. Similarly, BOD was reduced in the field. The results are given in the Table 11.

Table 9 Phycoremediation of Oil drilling effluent treated with *Chlorococcum humicola* : Scaled up tank

Parameters	Raw effluent	Effluent from scaled up tank treated with alga	% reduction
PHYSICAL EXAMINATION			
Turbidity NTU	56.3	7.3	**87.03**
Total solids mg/L	16564	3175	**80.83**
Total Dissolved Solids (TDS) mg/L	16492	3168	**80.79**
Total suspended solids (TSS) mg/L	72	7	**90.27**
Electrical conductivity (micro mho/cm)	23488	4501	**80.83**
CHEMICAL EXAMINATION			

pH	6.45	7.78	-
Alkalinity pH (as Ca CO_3) mg/L	0	0	0
Alkalinity total (as Ca CO_3) mg/L	390	310	20.51
Total Hardness (as Ca CO_3) mg/L	375	875	-
Calcium (as Ca) mg/L	90	200	-
Magnesium (as Mg) mg/L	36	90	-
Sodium (as Na) mg/L	525	810	-
Potassium (as K) mg/L	88	35	**60.22**
Iron (as Fe) mg/L	1.38	20	-
Manganese (as Mn) mg/L	nil	nil	nil
Free ammonia (as NH_3) mg/L	2.24	22	-
Nitrite (as NO_2) mg/L	nil	nil	-
Nitrate (as NO_3) mg/L	41	38	7.31
Chloride (as Cl) mg/L	351	896	-
Sulphate (as SO_4) mg/L	215	235	-
Phosphate (as PO_4) mg/L	3.42	6.48	-
Tidy's test (as O) mg/L	445.2	90	79.78
Silica (as SiO_2) mg/L	13.53	23	-
BOD mg/L	4710	320	**93.20**
COD mg/L	1050	892	**15.04**
Total Kjeldhal Nitrogen mg/L	3.36	114	-
Copper (as Cu) mg/L	0.00812	0.00628	**22.66**
Zinc (as Zn) mg/L	0.147	0.114	**22.44**
Chromium (as Cr) mg/L	0.00485	0.00410	**15.46**

Table 10 Calculation for the sludge removal in scaled up tank during algal treatment

Calculation for the sludge removal in scaled up tank during the algal treatment

Average pH : 6.15 ; Average TDS : 21412 mg/l

From 01.01.09 onwards to 11.05.09, effluent added to pilot scale : 102320 Liters

Initial TDS : 1524 mg/l X 44000 L = 67056000 mg

Added effluent TDS 21412 mg/l X 69320 L = 1484279840 mg

Added fresh water 820 mg/l X 9000 L = 7380000 mg

Final TDS : 40717 mg/l X 20000 L (-) = 814340000 mg(-)

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92320 L = 744295840 mg

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Sludge reduction = 744.295 kg / 92320 L Effluents = 8.06 g / L; Sludge reduction = 47.75 %

Table 11 Phycoremediation of micro alga in Oil drilling industrial effluent: A Comparison

Parameters	**Raw effluent**	**Effluent treated With Alga (lab)**	**Effluent from pilot slope tank treated with alga**	**Effluent from scaled up tank treated with alga**	**% Reduction (lab)**	**% Reduction (Pilot tank)**	**% Reduction (Scaled up tank)**
Physical Examination							
Turbidity NTU	56.3	23.2	42.5	7.3	**32.55**	24.51	**87.03**
Total solids mg/L	16564	15316	14544	3175	**7.53**	**12.19**	**80.83**
Total Dissolved Solids (TDS) mg/L	16492	15262	14410	3168	**7.45**	**12.62**	**80.79**
Total suspended solids (TSS) mg/L	72	54	134	7	**25**	-	**90.27**
Electrical conductivity (micro mho/cm)	23488	21770	20561	4501	7.31	12.46	**80.83**
Chemical Examination							
pH	6.45	7.20	7.48	7.78	-	-	-
Alkalinity pH (as Ca CO_3) mg/L	0	0	0	0	0	0	0
Alkalinity total (as Ca CO_3) mg/L	390	198	115	310	**49.23**	**70.51**	20.51
Total Hardness (as Ca CO_3) mg/L	375	975	5850	875	-	-	-
Calcium (as Ca) mg/L	90	210	1300	200	-	-	-
Magnesium (as Mg) mg/L	36	108	624	90	-	-	-
Sodium (as Na) mg/L	525	1725	6900	810	-	-	-
Potassium (as K) mg/L	88	175	850	35	-	-	**60.22**
Iron (as Fe) mg/L	1.38	1.56	22.64	20	-	-	-
Manganese (as Mn) mg/L	nil	nil	Nil	nil	Nil	Nil	nil
Free ammonia (as NH_3) mg/L	2.24	3.24	10.08	22	-	-	-
Nitrite (as NO_2) mg/L	nil	0.22	nil	nil	-	Nil	-
Nitrate (as NO_3) mg/L	41	9	48	38	**78.04**	-	7.31
Chloride (as Cl) mg/L	351	1224	6393	896	-	-	-
Sulphate (as SO_4) mg/L	215	200	9	235	6.97	**95.81**	-
Phosphate (as PO_4) mg/L	3.42	2.82	19.01	6.48	17.54	-	-
Tidy's test (as O) mg/L	445.2	43	328	90	**90.34**	26.32	79.78
Silica (as SiO_2) mg/L	13.53	32.47	49.38	23	-	-	-
BOD mg/L	4710	180	1400	320	**96.17**	**70.27**	**93.20**
COD mg/L	1050	502	3423	892	**52.19**	-	**15.04**
Total Kjeldhal Nitrogen mg/L	3.36	31.36	10.08	114	-	-	-
Copper (as Cu) mg/L	0.00812	0.00096	0.0080	0.00628	**88.17**	1.47	**22.66**
Zinc (as Zn) mg/L	0.147	0.090	0.143	0.114	**38.77**	2.72	**22.44**
Chromium (as Cr) mg/L	0.00485	0.00036	0.00485	0.00410	**92.57**	-	**15.46**

Conclusion:

Managing waste water is a major challenge in offshore and onshore oil drilling industries all over the world. The present investigation has resulted in developing a viable technology providing a permanent solution to this problem. Using micro algae to treat waste water has numerous advantages as has been demonstrated in the present investigation. Algal treatment technology (Phycoremediation) provides an excellent ecofriendly and cost effective system to reduce sludge, BOD and COD and many other wastewater parameters. This technology avoids all the chemicals which will be otherwise employed by industry in a conventional treatment process and indirectly saving lots of energy (fossil fuel) which is used to produce those chemicals. Growing algae in largescale at the industrial scale can also effectively scavenge CO_2.

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