Research Journal of Environmental Sciences

ISSN 1819-3412

Academic Journals Inc.

www.academicjournals.com

Research Journal of Environmental Sciences 2 (5): 408-414, 2008
ISSN 1819-3412

Decolourization of Paper Mill Effluent Using Hypersaline Cyanobacterium

[1]A. Nagasathya and [2]N. Thajuddin
[1]Department of Microbiology, J.J. College of Arts and Science,
Pudukkottai-622 404, Tamil Nadu, India
[2]Department of Microbiology, Bharathidasan University,
Tiruchirappalli -620 024, Tamil Nadu, India

Abstract: Biological treatment of wastewaters is a growing field of active research mainly by using microalgae including cyanobacteria. Hypersaline cyanobacterium *Phormidium tenue* KMD33 isolated from the saltpans of Kattumavadi and was maintained in Mn medium with 100 ppt of salinity. *P. tenue* KMD33 isolate was inoculated in the 250 mL conical flask containing 200 mL of each effluent samples collected from different locations of Paper Mill industry and were maintained in culture room, Department of Microbiology, J.J. College of Arts and Science, Pudukkottai, Tamil Nadu, India under white fluorescent lamp Among the physicochemical parameters studied initially and after 20 days of incubation period with *P. tenue* KMD33, considerable reduction in the levels of chloride, salinity, alkalinity, calcium, magnesium, nitrite, nitrate, inorganic phosphate, COD, BOD and sulphate and the increasing levels of pH, dissolved oxygen and electrical conductivity were observed. A significant change in the color reduction (from 60-90%) was recorded after 20 days of incubation period. This preliminary result showed that the hypersaline cyanobacterium *P. tenue* KMD33 is an efficient candidate for the removal of colour from the effluent.

Key words: Effluent, cyanobacteria, COD, BOD, salinity

INTRODUCTION

Pulp and paper rayon industries in general are one of the highly polluting industries in India. The increasing environmental concern has led many researchers to investigate the biotechnological potential of pulping in pulp manufacture to avoid the polluting effects of effluents (Hussain *et al*., 2003). Pulp and paper industry, generated large quantity of solid and liquid waste in its operation. The waste produced from this industry is mainly organic in nature, which is hazardous to the environment (Bist *et al*., 1994). These organic compounds are readily degraded in aqueous medium by soil and microorganisms present in the sewage. During this process, dissolved oxygen in the stream is used up. When dissolved oxygen is reduced below a certain limit, aquatic life is affected adversely. Colour in the liquid effluents also cuts the sunlight required for photosynthesis. Use of synthetic detergents in industries such as paper and pulp (containing lignin and lignosulphonates) gives rise to foam that is quite stable due to the presence of surfactant. Foams have the capacity to carry suspended solids as well as pathogenic bacteria (Bajpai and Bajpai, 1997). Pollution control measures involved are process modification as well as treatment of liquid wastes. The implant cost operating as well as capital generally decreases with the liquid waste volume but the treatment cost increases with the volume of paper produced.

Biological treatment of wastewaters is a growing field of active research and development in many countries, whether heavily industrialized or developing. Physiochemical techniques being costly, more

Corresponding Author: Nagasathya, A., Department of Microbiology, J.J. College of Arts and Science, Pudukkottai-622 404, Tamil Nadu, India Tel: 0091 04322 267593

or less efficient or leading to secondary pollution problems, biological treatments are appealing (de la Noüe and De Pauw, 1988). While considerable work has been carried out on the pretreatment, primary treatment and biological treatment of these wastewaters using ozone (Sinder and Porter, 1974), activated carbon (Dejohn, 1977; Ghosh *et al*., 1978), trickling filters and activated sludge processes and their modifications (Davis *et al*., 1977; Shriver and Dague, 1977). Very little information is available on the treatment of highly coloured and organic wastewaters by methods like oxidation ponds, aerated lagoons and stabilization ponds. (Oswald and Golueke, 1965; McGarry and Tongkasame, 1971; Brockett, 1977).

In recent years algae have been widely used as the test system for evaluating the extent of pollution caused by industrial effluents (Rai and Kumar, 1976). Algae being primary producers and occurring widely in almost all aquatic habitats serve as indicator of habitat condition (Rana *et al*., 1971; Palmer, 1980). Various pollution tolerant strains have been isolated and growth behavior of these selected strains were studied in the laboratory to evaluate the nutrient status of industrial effluents. (Rai and Kumar, 1976; Adhikary, 1987; Adhikary and Sahu, 1988). Some recent studies carried out by various researchers (Govindan and Sundaralingam, 1979; Govindan, 1982; Groves *et al*., 1979; Kobayashi and Yoshida, 1983; Jalal and Aziz, 1986; Rahaman and Aton, 1986; Srivastava *et al*., 1986) shown encouraging results in removing the colour from industrial waste waters by using algae.

The main aim is to treat the effluents emanating from Hindustan Newsprint Limited, Ernakulum, Kerala, India by using the hyper saline cyanobacteria *Phormidium tenue* (KMD 33).

MATERIALS AND METHODS

The effluent samples were collected from Hindustan Newsprint Limited, Kerala during the month of June 2004 from a different sampling sites such as Clarifier No.1 and 2, Cooling pond No.1 and 2, Lagoon, Final, Sanitary and Sludge which was classified as high solids. The samples were collected into a sterile borosilicate bottles. Samples were protected from sunlight during transportation. Physio-Chemical analysis of the effluent namely colour reduction, pH, chloride, salinity, total alkalinity, calcium, magnesium, sulphate, nitrate, nitrite, inorganic phosphorus, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and electrical conductivity was analysed following the methods given in APHA (1995) by analytical methods. The hypersaline cyanobacterial isolate namely, *Phormidium tenue* (KMD 33) isolated from the saltpans of Kattumavadi 10° 21' N and 79° 22' E of Palk Strait region was maintained in Mn medium with 100 ppt of salinity. The *P. tenue* (KMD 33) isolate was inoculated in the 250 mL conical flask containing 200 mL of each unsterile effluent samples collected from different locations namely Clarifier 1 and 2, Cooling pond 1 and 2, Lagoon, Sanitary and Final. The flasks were maintained in culture room Department of Microbiology, J.J. College of Arts and Science, Pudukkottai, Tamil Nadu, India under white fluorescent lamp (1400 lux): 14±10 L/D at 25±2°C. The results obtained before and after treating with *P. tenue* (KMD 33) were statistically analyzed by using paired t-test and correlation analysis (SPSS Version 10).

RESULTS

Among the physicochemical parameters studied, chloride, salinity, total alkalinity, calcium, magnesium, nitrite, nitrate, Inorganic phosphate, COD, BOD and sulphate were showed reduced concentration while pH, dissolved oxygen and electrical conductivity showed increased concentration after treating with *P. tenue* (KMD 33) (Table 1a-c). There was a drastic change in the colour reduction before and after treatment in various collecting spots, viz., clarifier 1 and 2, cooling pond 1 and 2, Lagoon, Sanitary and Final.

Table 1a: Physicochemical characteristics of paper mill effluent before and after treating with *Phormidium tenue* (KMD 33)

Physico chemical factors (mg L^{-1})	Clarifier No. 1		Clarifier No. 2	
	Before	After	Before	After
Colour	Brownish	Pale yellow	Brownish	Pale yellow
Optical density	0.1350±0.5[ac]	0.0300±0.1[ac]	0.257±0.5[ac]	0.074±0.1ac
pH	5.9000±0.18[bd]	7.1000±2.85[bd]	7.000±0.18[bd]	7.400±2.85[bd]
Chloride	1290.7±39[ac]	1099.7±32[ac]	404.2±39[ac]	255.3±32[ac]
Salinity (ppt)	32.900±8.8[ac]	28.100±8.3[ac]	10.32±8.8[ac]	6.520±8.3[ac]
Total alkalinity	60.000±0.46[ad]	60.000±0.86[ad]	80.00±0.46[ad]	40.00±0.86[ad]
Calcium	800.00±0.96[ad]	400.00±0.71[ad]	1200.±0.96[ad]	1200.±0.71[ad]
Magnesium	240.00±0.28[ac]	Nil	360.0±0.28 [ac]	120.0±0.96[ac]
Dissolved oxygen	0.3130±0.13[bc]	2.1440±0.60[bc]	0.256±0.13[bc]	2.859±0.60[bc]
Chemical oxygen demand	248.00±43.0[bc]	136.00±8.5[bc]	264.0±43.0[bc]	140.0±8.5[bc]
Biological oxygen demand	3.4000±0.78[ac]	2.8000±0.78[ac]	1.550±0.78[ac]	0.920±0.78[ac]
Sulphate	38.500±5.4[bc]	3.0000±0.6[bc]	47.20±5.4[bc]	2.000±0.6[bc]
Nitrate	3.0000±1.1[bc]	NIL	1.000±1.1[bc]	NIL
Nitrite	6.0000±1.6[ad]	1.5000±0.55[ad]	1.700±1.6[ad]	0.500±0.55[ad]
Inorganic phosphorus	16.500±4.7[ac]	NIL	15.00±4.7[ac]	2.500±0.9[ac]
EC (dS m^{-1})	3.2900±0.98[ac]	3.5900±1.0[ac]	0.860±0.98[ac]	1.230±1.0[ac]

Values are mean±SD from ten replicates; [a]: Values followed by identical letter(s) in the same row are positively correlated; [b]: Values followed by identical letter(s) in the same row are negatively correlated; [c]: Values followed by identical letter(s) in the same row are statistically significant; [d]:Values followed by identical letter(s) in the same row are not statistically significant

Table 1b: Physicochemical characteristics of paper mill effluent before and after treating with *Phormidium tenue* (KMD 33)

Physico chemical factors (mg L^{-1})	Cooling pond 1		Cooling pond 2	
	Before	After	Before	After
Colour	Brownish	Pale yellow	Brownish	Pale yellow
Optical density	0.630±0.5[ac]	0.065±0.1[ac]	0.399±0.5[ac]	0.032±0.1[ac]
pH	6.300±0.18[bd]	7.400±2.85[bd]	6.300±0.18[bd]	7.200±2.85[bd]
Chloride	333.3±39[ac]	219.8±32[ac]	609.9±39[ac]	546.0±32[ac]
Salinity (ppt)	8.540±8.8[ac]	5.640±8.3[ac]	15.60±8.8[ac]	13.90±8.3[ac]
Total alkalinity	220.0±0.46[ad]	160.0±0.86[ad]	200.0±0.46[ad]	60.00±0.86[ad]
Calcium	600.0±0.96[ad]	600.0±0.71[ad]	600.0±0.96[ad]	400.0±0.71[ad]
Magnesium	Nil	Nil	Nil	Nil
Dissolved oxygen	0.634±0.13[bc]	2.430±0.60[bc]	0.450±0.13[bc]	3.573±0.60[bc]
Chemical oxygen demand	256.0±43.0[bc]	160.0±8.5[bc]	196.0±43.0[bc]	144.0±8.5[bc]
Biological oxygen demand	1.440±0.78[ac]	0.860±0.78[ac]	2.400±0.78[ac]	1.780±0.78[ac]
Sulphate	36.50±5.4[bc]	3.500±0.6[bc]	46.00±5.40.6[bc]	3.000±0.6[bc]
Nitrate	NIL	1.000±0.37	NIL	NIL
Nitrite	1.000±1.6[ad]	0.500±0.55[ad]	1.900±1.6[ad]	1.000±0.55[ad]
Inorganic phosphorus	10.00±4.7[ac]	3.000±0.9[ac]	15.00±4.7[ac]	2.500±0.9[ac]
EC (dS m^{-1})	0.520±0.98[ac]	0.350±1.0[ac]	2.150±0.98[ac]	2.320±1.0[ac]

Values are mean±SD from ten replicates; [a]: Values followed by identical letter(s) in the same row are positively correlated; [b]: Values followed by identical letter(s) in the same row are negatively correlated; c: Values followed by identical letter(s) in the same row are statistically significant; [d]: Values followed by identical letter(s) in the same row are not statistically significant

The statistical analysis was carried out to know significant difference before and after treating the effluent. The colour, chloride, salinity, total alkalinity, calcium, magnesium, nitrite, inorganic phosphate, biological oxygen demand and electrical conductivity were showing positive correlation and pH, dissolved oxygen, chemical oxygen demand, sulphate and nitrate were showing negative correlation. In paired t-test, the calculated value was higher than the tabulated value in the parameters namely, colour, chloride, salinity, magnesium, inorganic phosphate, biological oxygen demand, electrical conductivity, dissolved oxygen, chemical oxygen demand, Sulphate and nitrate. Hence the null hypothesis was rejected i.e., it has been inferred that the above parameters showing significant difference between before and after treatment. The rest of the parameters like pH,

Table 1c: Physicochemical characteristics of paper mill effluent before and after treating with *Phormidium tenue* (KMD 33)

Physico chemical factors (mg L^{-1})	Lagoon		Sanitary		Final	
	Before	After	Before	After	Before	After
Colour	Brownish	Transparent	Transparent	Transparent	Light brown	Transparent
Optical density	0.348 ± 0.5^{ac}	0.004 ± 0.1^{ac}	0.091 ± 0.5^{ac}	0.009 ± 0.1^{ac}	0.240 ± 0.5^{ac}	0.005 ± 0.1^{ac}
pH	7.200 ± 0.18^{bd}	7.200 ± 2.85^{bd}	6.800 ± 0.18^{bd}	7.700 ± 2.85^{bd}	7.400 ± 0.18^{bd}	7.400 ± 2.85^{bd}
Chloride	709.2 ± 39^{ac}	439.7 ± 32^{ac}	234.0 ± 39^{ac}	120.5 ± 32^{ac}	624.0 ± 39^{ac}	354.6 ± 32^{ac}
Salinity (ppt)	18.13 ± 8.8^{ac}	11.26 ± 8.3^{ac}	6.000 ± 8.8^{ac}	3.100 ± 8.3^{ac}	15.90 ± 8.8^{ac}	9.080 ± 8.3^{ac}
Total alkalinity	200.0 ± 0.46^{ad}	40.00 ± 0.86^{ad}	40.00 ± 0.46^{ad}	40.00 ± 0.86^{ad}	40.00 ± 0.46^{ad}	40.00 ± 0.86^{ad}
Calcium	600.0 ± 0.96^{ad}	600.0 ± 0.71^{ad}	1000 ± 0.96^{ad}	1000 ± 0.71^{ad}	1000 ± 0.96^{ad}	1000 ± 0.71^{ad}
Magnesium	360.0 ± 0.28^{ac}	240.0 ± 0.96^{ac}	480.0 ± 0.28^{ac}	120.0 ± 0.96^{ac}	600.0 ± 0.28^{ac}	240.0 ± 0.96^{ac}
Dissolved oxygen	0.441 ± 0.13^{bc}	1.858 ± 0.60^{bc}	0.491 ± 0.13^{bc}	1.715 ± 0.60^{bc}	0.314 ± 0.13^{bc}	2.573 ± 0.60^{bc}
Chemical oxygen demand	164.0 ± 43.0^{bc}	144.0 ± 8.5^{bc}	164.0 ± 43.0^{bc}	156.0 ± 8.5^{bc}	194.0 ± 43.0^{bc}	148.0 ± 8.5^{bc}
Biological oxygen demand	2.000 ± 0.78^{ac}	1.320 ± 0.78^{ac}	2.000 ± 0.78^{ac}	1.250 ± 0.78^{ac}	0.970 ± 0.78^{ac}	0.350 ± 0.78^{ac}
Sulphate	38.50 ± 5.4^{bc}	3.500 ± 0.6^{bc}	32.20 ± 5.4^{bc}	3.000 ± 0.6^{bc}	35.00 ± 5.4^{bc}	2.000 ± 0.6^{bc}
Nitrate	NIL	NIL	NIL	NIL	NIL	NIL
Nitrite	1.700 ± 1.6^{ad}	1.000 ± 0.55^{ad}	2.000 ± 1.6^{ad}	NIL	1.500 ± 1.6^{ad}	1.500 ± 0.55^{ad}
Inorganic phosphorus	5.000 ± 4.7^{ac}	2.500 ± 0.9^{ac}	5.000 ± 4.7^{ac}	2.500 ± 0.9^{ac}	10.00 ± 4.7^{ac}	2.500 ± 0.9^{ac}
EC (dS m^{-1})	1.000 ± 0.98^{ac}	1.250 ± 1.0^{ac}	1.520 ± 0.98^{ac}	1.840 ± 1.0^{ac}	0.730 ± 0.98^{ac}	0.970 ± 1.0^{ac}

Values are mean±SD from ten replicates; [a]: Values followed by identical letter(s) in the same row are positively correlated; [b]: Values followed by identical letter(s) in the same row are negatively correlated; [c]: Values followed by identical letter(s) in the same row are statistically significant; [d]: Values followed by identical letter(s) in the same row are not statistically significant

total alkalinity, calcium and nitrate were having lower t-value than that of the tabulated value and therefore there is no significant difference between before and after treatment when considering these parameters.

DISCUSSION

The cyanobacteria is capable of producing oxygen during photosynthesis, high level tolerance of various pollutants, large surface area offered by the minute cells make them highly suitable for effluent treatment (Oswald *et al*., 1978). There are several review papers on wastewater treatment with microalgae (Abeliovich, 1986; de la Noüe *et al*., 1986, 1990; Mara and Pearson, 1986; Pantastico, 1987; de la Noüe and DePauw, 1988; Oswald, 1988 a, b, c; Huntley *et al*., 1989; Redalje *et al*., 1989).

The *P. tenue* KMD 33 isolated from the saltpans of Kattumavadi of Palk Strait region was used for the treatment of the papermill effluent, since it shows high tolerance and versatility nature. Pouliot *et al*. (1989) stated that the filamentous type of cyanobacteria having many advantages, viz., the simplicity of harvesting by sedimentation, the epiphytic nature of *Phormidium*, resistant to contamination by other kinds of algae and the culture composition therefore remains stable, utilization of CO_2 more efficiently than chlorophyceae.

When treating with *P. tenue* KMD 33 in the papermill effluent, the acidic pH level was changed and maintained to neutral (pH 7-7.4). Gomyo *et al*. (1972) reported that increased pH leads to oxidative discoloration of the effluents. It was observed that *P. tenue* treated effluent leads in the reduction of chloride, salinity, total alkalinity, calcium, magnesium, sulphate, nitrite, nitrate and inorganic phosphate (Table 1a-c). Many studies have demonstrated the success of using algal cultures to remove nutrients from wastewaters rich in nitrogenous and phosphorus compounds (Neos and Varma, 1966; Kalisz, 1974; Saxena *et al*., 1974; Matusiak *et al*., 1976; Oswald *et al*., 1978; Chan *et al*., 1979; de la Noüe and Proulx, 1988) and hence have been used in stabilization pond (Gloyns, 1971), in lagoons (Neel *et al*., 1961) and in tertiary treatment of sewage (Hemens and Mason, 1968; Knapp, 1971) for the removal of pollutants from the wastewater. There was a drastic reduction in the BOD and COD content of the treated effluent (Table 1a-c). As stated by Nandan *et al*. (1990) microbial methods increasingly used for the reduction of BOD and COD. More than 95% reduction of BOD have already been reported by Manoharan and Subramanian (1993) in Ossein effluent and papermill effluent by using *Oscillatoria pseudogeminita var granulata* and Kumar *et al.* (1997) observed 57% reduction of COD of anaerobically digested distillery spent wash. A significant increase in dissolved oxygen was observed in the effluent (Table 1a-c). The use of algae in wastewater treatment could prove beneficial in different ways since they bring about oxygenation and mineralization in addition to serving as food source for aquatic species (Elnabarawy and Welter, 1984). Srinivasan (1959) reported that *Chlorella, Hydrodictyon, Scenedesmus* and *Mastigocladus* showed oxygen-donating capacities in distillery wastes.

The main aim of the present study was to remove the colour of the papermill effluent on treating with *P. tenue* (KMD 33). A significant colour reduction was observed on 20th day of the treatment. (Table 1a-c). As reported by Dohanyos *et al.* (1978), the removal of dyes from wastewaters by biological process is physical and/or physico-chemical in nature. Adsorption onto the surface of the microorganisms was cited as the primary mechanism of dye removal by the activated sludge (Davis *et al*., 1977; Dohanyos *et al*., 1978). Though the result of the preliminary study was promising further systematic field level, large-scale experiments are needed before a technology can be perfected.

ACKNOWLEDGMENT

Authors are thankful to the management of J.J. College of Arts and Science, Pudukkottai, for providing the research facilities.

REFERENCES

Abeliovich, A., 1986. Algae in Wastewater Oxidation Ponds. In: Handbook of Microbial Mass Culture, Richmond, A. (Ed.). CRC Press, Boca Raton, pp: 331-338.

Adhikary, S.P., 1987. Growth response of *Cealothrix marchica* Lemm. To exogenous organic substrates and distillery effluent in the light and dark. J. Basic Microbiol., 27: 475-481.

Adhikary, S.P. and J. Sahu, 1988. Ecophysiological studies on ensheathed blue-green algae in a distillery effluent polluted area. Environ. Ecol., 6: 915-918.

APHA, 1995. Methods for the Examination of Water and Wastewater. Clesceri, L.S., A.E. Greenberg and A.D. Eaton (Eds.). 20th Edn. American Public Health Association, Washington, D.C., pp: 20-100.

Bajpai, P. and P.K. Bajpai, 1997. Reductions of Organo Chlorine Compounds in Bleach Effluents. Adv. Biochem. Eng. and Biotech. Eriksson, K.E.L. (Ed.). Springer Berlin, Heidelberg, 57: 213-259.

Bist, V., S. Chand, S.S.G. Sekar, A.G. Kulkarni and R. Pant, 1994. Recovery of energy through anaerobic treatment of organic waste from paper industry. Proceeding of National Workshop on Urban Municipal and Industrial Waste for Energy Recovery. Regional Research Laboratory, 10-11 March, Bhubaneshwar, pp: 78-89.

Brockett, O.D., 1977. Some causes of biological instability and their effects on algal population levels in waste treatment lagoons. Proc. Wat. Tech., 19: 941-948.

Chan, K.Y., K.H. Wong and P.K. Wong, 1979. Nitrogen and phosphorus removal from sewage effluent with high salinity by *Chlorella salina.* Environ. Pollut., 18: 139-146.

Davis, G.M., J.H. Khoon and C.E. Adams, 1977. Treatment of two textile dye house wastewaters. Proceeding 32nd. Purdue Ind. Waste Conference, May 10, 11 and 12, pp: 918-997.

de la Noue, J., D. Proulx, R. Guay, Y. Pouliot and J. Turcotte, 1986. Algal biomass Production from Wastewaters and Swine manure: Nutritional and Safety Aspects. In: Microbial Biomass Protein, Elsevier. Moo-Young, M. and K.F. Gregory (Eds.). Applied Science, London, pp: 141-145.

de la Noue, J. and D. Proulx, 1988. Biological tertiary treatment of urban wastewaters with chitosan immobilized *Phormidium*. Applied Microbial. Biotechnol., 29: 292-297.

de la Noüe, J. and N. De Pauw, 1988. The potential of microbial biotechnology. A review of production and usage of microalgae. Biotech. Adv., 6: 725-770.

de la Noue, J., P. Chevalier and D. Proulx, 1990. Effluent Treatment with Immobilized Microalgae and Cyanobacteria: A Critical Assessment. In: Wastewater Treatment by Immobilized Cells, Tyagi, R.D. and K. Vembu (Eds.). CRC Press, Boca Raton, pp: 143-152.

Dejohn, P.B., 1977. Factors consider when treating dye wastes with granular activated sludge. J. Prog. Wat. Tech., 10: 559-575.

Dohanyos, M., V. Madera and M. Sedlacek, 1978. Removal of organic dyes by activated sludge. J. Prog. Wat. Tech., 10: 559-575.

Elnabarawy, M.T. and A.N. Welter, 1984. Utilization of Algal Cultures and Assays by Industry. In: Algae as Ecological Indicators, Shubert, L.E. (Ed.). Academic Press. Inc., New York, pp: 317-328.

Ghosh, M.M., F.E. Woodward and O.J. Sproul, 1978. Treatability studies and design consideration for textile mill waste water. J. Water Pollut Control Federation, 50: 14-16.

Gloyns, E.F., 1971. Waste stabilization ponds. Monogr.Ser. W.H.O. No. 61, pp: 22.

Gomyo, T., H. Kato, K. Udaka, M. Horikoshi and M. Fujimaki, 1972. Chemical studies on melanoidins Part III. Effects of heating on chemical properties of melanoidin prepared from Glycine-Xylose system. Agric. Biol. Chem., 36 (1): 125-132.

Govindan, V.S. and V.S. Sundaralingam, 1979. Studies on the treatment of textile mill wastewater by stabilization pond method. Ind. J. Environ. Health, 21: 321-331.

Govindan, V.S., 1982. Studies on algae in relation to treatment of textile mill waste water. J. Asian Environ., 4: 28-32.

Groves, G.R., C.A. Buckley and R.W. Turnbull, 1979. Closed looped recycle systems of textile effluents. J. Water Pollut Control Federation, 51 (3): 499-517.

Hemens, J. and H.M. Mason, 1968. Sewage nutrient removal by a shallow algal stream. Water Res., 2: 277-287.

Huntley, M.E., A.M. Nonomura and J. De la Noüe, 1989. Algal culture Systems. In: Biotreatment of Agricultural Wastewater, Huntley, M.E. (Ed.), CRC Press, Boca Raton, pp: 111-130.

Hussain, S.K.M., M. Das and S.H. Ibrahim, 2003. Studies in Biopulping of Bagasse using *Phanerochacte chrysosporium*. J. Ind. Pollut. Control, 19 (2): 255-269.

Jalal, K.F. and M.A. Aziz, 1986. Pollution control from agro based and small scale industries of the ESCAP region. Proc. Int. Conf. Waste Wat. Waste. Manage. Asia. Aug 29-Sep 2, Singapore, pp: 65-81.

Kalisz, L., 1974. Role of algae in sewage purification. I. Oxygen production; II. Nutrient removal. Pollut. Arch. Hydrobiol., 20: 389-484.

Knapp, C.E., 1971. Recycling sewage biologically. Environ. Sci. Technol., 5: 111-112.

Kobayashi, M. and T. Yoshida, 1983. Recycling of organic waste material. Proc. Int. Symb. Biomass Utilz. Trop, Areas, Okinawa Japan, Sep 21, 22 and 23, pp: 76-88.

Kumar, V., L. Wati, F. Fitzgibbon, P. Nigam, I.M. Banat, D. Singh, B.Y. Lee, K.W. Lee, M.G. Mc Garry and M. Graham, 1997. Overview of wastewater treatment and resource recovery. Report-workshop on High rate Algae Pond Systems, April 21-22, pp: 31-38.

Manoharan, C. and G. Subramanian, 1993. Influence of effluents on fatty acid content of a cyanobacterium. Curr. Sci., 65: 353-354.

Mara, D.D. and H. Pearson, 1986. Artificial Freshwater Environment: Waste Stabilization Ponds. In: V Biotechnology, CH Verlag Sgesellschaft, Rehon, H.J. and G. Reed (Eds.). Weinheim, Germany, pp: 177-206.

Matusiak, K., M. Pryztocka-Jusiak, K. Leszczynska-Gerula and M. Horoch, 1976. Studies on the purification of wastewater from the nitrogen fertilizer industry by intensive algal cultures, II. Removal of nitrogen from wastewater. Acta Microbiol. Pol., 25: 361-374.

Mc Garry, M.G. and C. Tongkasame, 1971. Water reclamation and algae harvesting. J. Water Pollut. Control Federation, 43: 824-830.

Nandan, R., V. Tondwalkar and P.K. Ray, 1990. Biomethanation of spent wash, Heavy metal inhibition of methanogenesis in synthetic medium. J. Ferment. Bioeng., 69 (5): 276-281.

Neel, J.K., J.H. Mc Dermott and C.A. Monday, 1961. Experimental lagooning of raw sewage at Fayette, Missouri. J. Water Pollut. Control Federation, 36: 603-612.

Neos, C. and M.M. Varma, 1966. The removal of phosphate by algae. Water and Sewage Works, 112: 456-459.

Oswald, W.J. and C.G. Golueke, 1965. Harvesting and processing sewage-grown planktonic algae. J. Water Pollut. Control Federation, 37: 471-478.

Oswald, W.J., E.W. Lee, B. Adan and K.H. Yao, 1978. New wastewater treatment method yields a harvest of saleable algae. WHO Chronicle, 32: 348-350.

Oswald, W.J., 1988a. The Role of Microalgae in Liquid Waste Treatment and Reclamation. In: Algae and Human Affairs, Lembi, C.A. and J.R. Waaland (Eds.). Cambridge U.P., Cambridge, pp: 255-281.

Oswald, W.J., 1988b. Micro-Algae and Wastewater Treatment. In: Micro-Algal Biotechnology, Borowitzka, M.A. and L.J. Borowitzka (Eds.). Cambridge U.P., Cambridge, pp: 305-328.

Oswald, W.J., 1988c. Large-scale Culture Systems (engineering aspects) In: Micro-Algal Biotechnology, Borowitzka, M.A. and L.J. Borowitzka (Eds.), Cambridge U.P., Cambridge, pp: 357-394.

Palmer, C.M., 1980. Algae and Water Pollution. Castle House Publications. England, pp: 34-42.

Pantastico, J.B., 1987. Algal production in wastewater: Progress and problems. Arch. Hydrobiol., 28: 105-121.

Pouliot, Y., G. Buelna, C. Racine and J. De la Noüe, 1989. Culture of cyanobacteria for tertiary wastewater treatment and bioman production. Biol. Wastes, 29: 81-91.

Rahaman, A.R. and A. Aton, 1986. Biological treatment textile finishing wastewaters. Proc. Reg. Workshop. Ecol. Microb. Processor. Mixed Flora, Bandug, Indonesia. June 15 and 16, pp: 62-66.

Rai, L.C. and H.D. Kumar, 1976. Algal growth as a means of evaluation of nutrient status of the effluent of a fertilizer factory near Sahapuri, Varanasi. Trop. Ecol., 17: 50-56.

Rana, B.C., T. Gopal and H.D. Kumar, 1971. Studies to biological effects of industrial wastes on growth on growth of algae. Environ. Health, 13: 138-143.

Redalje, D.G., E.O. Duerr, J. De La Noüe, P. Mayzaud, A.M. Nonomura and R.C. Cassin, 1989. Algae as Ideal Waste Removers: Biogeochemical Pathways. In: Biotreatement of Agricultural Wastewater, Huntley, M.E. (Ed.), CRC Press, Boca Raton, pp: 91-110.

Saxena, P.N., A. Tewari and M.A. Khan, 1974. Effect of *Anacystis nidulans* on the physico-chemical and biological characteristics of raw sewage. Proc. Indian Acad. Sci., 79: 139-146.

Shriver, L.E. and R.R. Dague, 1977. Textile Dye Process Waste Treatment with reused consideration. Proceeding 32nd Purdue Ind. Waste Conference, 1 May 10, 11 and 12, pp: 581-592.

Sinder, E.H. and J.J. Porter, 1974. Ozone treatment of dye water. J. Water Pollut. Control Federation, 46: 886-894.

Srinivasan, M.V., 1959. Some observations on the use of algae for treatment of distillery wastes. Proceeding Symposium Algology, ICAR., Jan 4 and 5, pp: 302-307.

Srivastava, A., R.P. Mathur, R. Vargava and J.P. Singh, 1986. Limiting factors in animal waste fed stabilization ponds. J. Inst. Engrs. India, 66 (3): 101-104.