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REVIEW

Study of Biological Treatment of Paper-Pulp Effluent

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The waste effluents discharged by the paper pulp industry contain variety of toxic contaminants which have gained a lot of attention worldwide because this is regarded as major source of pollution. Various methods have been used to reduce COD, BOD, lignin, phenol, colour *etc*. from textile effluent by many researchers which include chemical oxidation, Fenton's process, ozonation, wet air oxidation, hydrogen peroxide oxidation, bio-degradation, *etc*. In this review paper we have mainly focused on the biological methods which are eco-friendly and efficient. The scattered research work related with the biological treatment of textile effluent has been compiled to explore the most suitable, eco-friendly and efficient method for the removal of COD/BOD, phenol, lignin, colour, *etc*. along with their positive and negative aspects which would be helpful for the researchers and industries to explore new dimensions.

Keywords: Bio-degradation, Aerobic, Anaerobic, Lignin.

INTRODUCTION

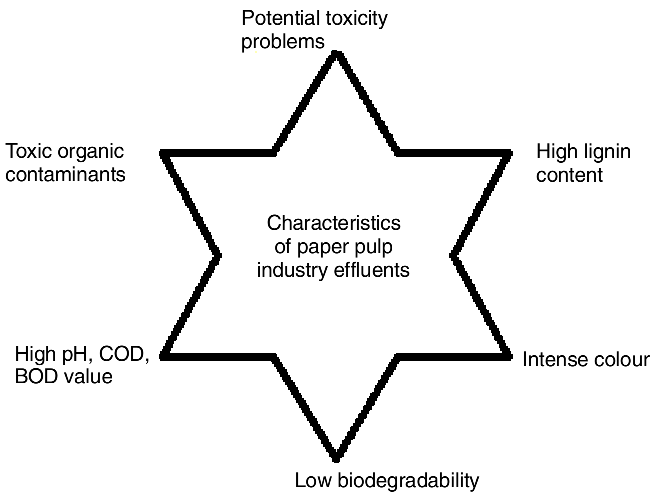
Paper industry is one of the oldest and largest industry, which consume huge amount of water to carry out production process with intake of some raw materials such as wood, cellulose, vegetables, baggase, fibres and waste paper *etc*. [1]. Production process discharges ton of wastewater loaded with toxic organic pollutants, high pH, COD, BOD value and dark bright colours. The colouring agents present in wastewater stream are organic in nature, consists of tannin resins, synthetic dyes and wood extractives [2]. In addition to these colouring agents, lignin is also responsible for colouration in industry effluents. Lignin is one of the woody feature of higher plants with high molecular weight that acts as binder (agent) to hold cells together. Presence of lignin imparts dark brown colour to the effluent and is non-degradable [3]. Inspite of colour, these are also responsible for increasing temperature of water and decreasing the rate of photosynthesis [4]. Hence, it has been regarded as most pollution generating industrial area that disturbs the ecological balance in environment. Rapidly increasing population and to meet increasing demands have established many more industries, giving birth to such many environmental issues. Numerous treatment processes have been existing worldwide to treat paper pulp industrial effluents such as distillation, chemical oxidation, Fenton's process, ozonation, wet air oxidation, hydrogen peroxide oxidation [5], *etc*. but application of these processes have been limited by a number of new arising problems associated with them such as their high operating cost, sludge generation and they have also been found with unsatisfactory results for COD and BOD reduction. To limit these existing problems researchers switch on to the biological treatment strategy that has been found to be satisfactory in the reduction of BOD/COD amount along with greater degradation of lignin and its derivatives. Inspite of all these issues industrial effluents is causing severe hazard to the aquatic life. Hence, there is dire need of adopting any eco-friendly and efficient technique in order to reduce these hazards.

This paper reviews the bio-degradation strategy consisting aerobic/anaerobic treatment, enzymatic, bacterial and fungal treatment for the reduction of BOD/COD, colour, lignin and phenol from paper pulp industry because this method is comparatively more promising.

Characteristics of industrial effluent:

• High concentration of insoluble pollutants that do not settle down easily.

• Soluble pollutants at variable concentration BOD = 100-1000 mg/L and COD = 300-4000 mg/L.



- Presence of phenolic compounds.
- Presence of intense brown colour due to lignin and its derivatives.

Source of colour: Colour in paper pulp industry comes from lignin and its derivatives. Paper making generates colourless effluent carrying a bit of dyes [6]. The major contribution is being made by pulp mill processing. Bleaching unit is one other colour source, where scope of reusing filterate is very little. Among the effluents, caustic filterate extraction stage is highest coloured effluent [7].

Biological treatment method: Most of the researchers have focussed on eco-friendly and energy saving technique for the wastewater treatment. Therefore, they have implied biological approach for the removal of undesirable contaminants from the industrial effluents of paper-pulp mill. Biological treatment helps in the reduction of colour, COD, BOD and low molecular weight toxic derivatives. This treatment strategy has been found to be inexpensive, simply designed and environmental friendly. The following are some of the biological strategies that have been implied for the treatment process of effluent along with their advantages and disadvantages.

Aerobic treatment: Aerobic treatment includes aerobic activity of micro-organisms in the presence of oxygen to carry out their metabolic activity. Oxygen is supplied in the form of air to carry out degradation of oxygen demanding organic components. Aerobic treatment produces CO_2 green house gas and large quantity of sludge through the removal of carbonaceous material. Production of green house gas can be estimated by the CO_2 emmision from removal of BOD and biomass decay [7].

$$\text{Green house gas emission} = CO_{2\,(\text{from BOD removal})} + CO_{2\,(\text{from microbial biomass decay})}$$

There are number of aerobic systems available for the treatment methodology such as aerated lagoons, activated sludge system, bio-film process, *etc*. [8].

Aerated lagoon: Use of aerated lagoon is a biological treatment method used by many researchers for paper pulp effluents. A lagoon is basically large shallow pond where biological treatment of wastewater has been carried out with active microbes and mechanical aeration. This strategy is easy to operate and maintained along with high load capacity but, it is space consuming with residence time of 5-7 days and moreover large energy is required for aeration. Some aerated lagoons have been modified into long term activated sludgers (LAS) having short residency of 1 day [9]. Several workers [10-12] treated wastewater of pulp paper mill with aerated lagoon and found to have 30-40 % COD reduction and 50-70 % BOD reduction. Bryant [13] set up the treatment process for paper pulp effluent with aerated lagoon and reported 67 % COD reduction, but nitrogen supply could effects the degradation efficiency of contaminants.

Activated sludge process: This process is generally carried out in 2 steps. Firstly, wastewater is treated with high concentration of microbes and strong aeration facility for few hours or a day. Secondly, separation of water and sludge, has been done in sedimentation basin followed by re-circulation of sludge that enables high concentration of microbes for extensive reduction of organic compound. The advantage of this system is that there is controlled degree of degradation but, this approach failed to uptake fast load changes and also high sludge generation [14]. Maximum removal efficiency *i.e.* 95 % COD reduction has been monitored by anaerobic treatment with activated sludge process as reported by Bengtsson *et al.* [15]. Some other investigators [16-18] treated wastewater of pulp and paper mill and high reduction efficiencies for COD, BOD *i.e.* 70 and 90 % has been reported with activated sludge method.

Anaerobic treatment: Anaerobic treatment process involves anaerobic activity without oxygen to carry out the degradation process [19]. Anaerobic process produces methane gas, having 34 times more global warming potential than CO_2 gas [20]. But, if generated methane gas is recovered and used as a energy source then the anaerobic treatment process could be cost effective than the aerobic treatment process. Moreover, green house gas (GHG) emission during anaerobic treatment is little less than during aerobic treatment because of lower volume of sludge generation [7,20].

$$\text{GHG emission} = CO_{2\,(\text{from BOD removal})} + CO_{2\,(\text{from biomass decay})} + CO_{2\,(\text{CH4 combustion})} + CO_{2\,(\text{CH4 leakage})}$$

Among anaerobic treatment methods UASB reactor (up-flow anaerobic sludge blanket) and FBB (fluidized bed reactor) have been tried out for the treatment of paper pulp wastewater [21].

Chen and Horan [21] examined the use of UASB reactor for the treatment of newsprint paper mill effluents for the COD removal with 66 % and sulphite removal with 73 %. The generation of methane gas and sludge has been monitored during COD removal. Chinnaraj and Venkoba Rao [22] used USAB reactor for the treatment strategy with 80-93 % removal efficiency for COD. Buzzini and Pires [23] also tried USAB reactor for the treatment of bleached and unbleached effluents with 79-82 % COD removal and 71-99 % chlorinated organics. USAB reactors have also been used by Rintala and Lipisto [24] for the treatment process. The results have been monitored for COD removal at different temperature ranges *i.e.* 82 % removal at 35 °C, 92 % removal at 55 °C and 86 % removal at 65 °C [24]. Deshmukh *et al.* [25] tried up-flow anaerobic filter (UAF) for the treatment of bleaching wastewater. The BOD and COD removal efficiency has been monitored with 70 and 50 % respectively.

Enzymatic treatment: Microbes have been engineered to produce enzymes which otherwise do not possess high enzyme activity. Enzymatic treatment method has been used as a primary treatment or in combination with biological unit. Among the enzymes, oxidoreductase like laccases, tyrosinases and per-oxidases have the capability to carry out removal of colour and phenolic compounds in bleaching effluent [26]. This method enlists no. of advantages such as ease of control, low generation of sludge, effectiveness over a heavy load of concentration, pH and less contact time. This treatment strategy involves polymerization of target toxic contaminants without breakdown until products reach their point of precipitation.

Tyrosinases and laccases are both copper containing enzymes. *o*-Hydroxylation of mono phenols to *o*-diphenols followed by the oxidation of *o*-diphenols to *o*-quinones has been carried out by tyrosinases enzyme [26,27]. Laccases enzyme activity has been initiated by molecular oxygen (4-electron) whereas, activity of heme-protein peroxidises (HRR) has been initiated by hydrogen peroxide (2-electron). They each carry out one electron oxidation of phenols to form phenoxy radicals which further couple non-enzymatically to form dimers [28].

Soyabean peroxidase (SBP) has received more attention than heme-protein peroxidase (HRP). Soyabean peroxidase has been found to be more effective than HRP enzyme for the removal of phenol [28,29]. Rezvani *et al*. [30] studied immobilized SBP for the removal of phenol in a semi-permeable alginate membrane with 97 % removal efficiency at 56 °C. Kurnik *et al.* [31] investigated another plant peroxidise, from potato pulp for the phenol removal. The removal efficiency has been found to be 90 % at pH 4-8, in 2 h reaction time. The removal efficiency seems to decrease at pH 10 value. Inactivation of the enzyme is also one of the shortcoming associated with enzymatic treatment.

Fungal treatment: Fungal species have been found to be most attractive to carry out bio-degradation of undesired contaminants. Research work has been more focused on white rot fungal sp. because of their powerful degrading enzyme activity system. Karn *et al.* [32] studied the bio-degradation of phenol using *Candida tropicalis* with 98.7 % removal efficiency. Nagarathnamma and Bajpai [33] utilized fungi *Rhizopus oryzae*, zygomycete, for detoxification of effluents. This fungal sp. shows 92-95 % colour removal, 50 % COD, 72 % adsorbable organic halides and 34 % extractable organic halides at temperature of 25-45 °C for 24 h at pH value 3-5 [33]. White rot fungal sp. *Fomes lividus* and *Trametes versicolor* have been tested for effluent treatment. The results for the removal of colour have been found to be 68 % with *Trametes versicolor* on 6th day and 59.32 % by *Fomes lividus* on 7th day incubation whereas, COD reduction has been achieved 59.3 % by both sp. [34]. The isolated fungi sp. *Trichoderma reesei* exhibit higher rate of degradation *i.e*. 99 % BOD removal and 80 % COD removal when used individually [35]. White rot fungal sp. has been also demonstrated by Saxena and Gupta [36] for the treatment strategy with 41 % COD reduction and 34 % colour degradation. Prasad and Gupta [37] have demonstrated two fungal sp. namely *T. versicolor* and *P. chrysosporium* for the treatment of effluent. Nearly about 78-79 % degradation efficiency for COD and 84-94 % colour reduction has been noticed with these fungal sp. One other fungal sp. known as *Trametes pubescens* has been investigated by Gonzalez *et al.* [38] to carry out bio-remediation with the degradation efficiency of 94.6 % for 2-chloro phenol and 67.8 % for pentachloro phenol [38]. Singhal and Thakur [39] also studied the colour reduction with 66.6 % efficiency and lignin degradation with 37 % efficiency with the application of *Emericella nidulans*. Treatment of wastewater effluent has also been carried out by Liu *et al.* [40] with the help of *Aspergillus niger* fungi and indicated the 60 % COD reduction and 43 % colour reduction. The COD reduction has also been indicated with other two fungal species namely *Rhizopus oryzae* and *Phanerochaete chrysosporium* with the reduction efficiency of 81-82 %, as reported by Frietas *et al.* [41]. Malaviya and Rathore [42] have also studied the applicability of *Fusarium sambucinum* to carry out biodegradation method and indicated the reduction efficiency of 89.4 % for COD, 78.6 % for colour and 79 % for lignin. Nearly about 74-81 % COD reduction of waste effluent of Kraft pulp mill has been reported by Frietas *et al.* [41] in his experiment. Fungal cellobiose dehydrogenate has been explored by Wingate *et al.* [43] for the treatment of waste effluent and 50 % colour reduction has been reported in his work. The biodegradation efficiency of effluent has also been observed with the application of *Schizophyllum commune* fungi by Senthilkumar *et al.* [44] and it has been found to have 98 % colour reduction, 70 % BOD reduction and 72 % COD reduction within two days at pH value 4-5 [2]. Saritha *et al.* [45] have reported bioremediation of effluent by using *Phanerochacte chrysosporium* and *Trametes hirsute* fungal species and are capable of reducing colour with 78.6 % efficiency, lignin degradation with 79 % and COD reduction with 89.4 % efficiency within 21 days incubation [45]. One other fungi known as *Tinctoria borbonica* has been stimulated by Tiku *et al.* [46] for the treatment of effluent. Nearly about 25 % COD reduction and 85 % colour reduction has been reported within 3 days of incubation at pH = 4 [46]. One other soil saprophyte known as *Gliocladium vireus* has been found to carry out bioremediation of effluent of paper-pulp mill. It has been noticed reduction efficiency of 42 % for colour, 52 % for lignin and 65 % for BOD, as reported by Kamali and Khodaparsat [2]. One other white rot fungal sp. *Coriolus versicolor* known for the decolourization of effluent within 60 % colour reduction efficiency as reported by Tiku *et al.* [46]. Biodegradation of effluent has also been carried out with *Cryptococcus fungi* with 27 % reduction efficiency for colour, 24 % degradation efficiency for lignin, as reported by Singhal and Thakur [47]. Fungal sp. known as *Aspergillus foetidus* has also been studied by Sumathi and Pathak [48] for its ability to reduce colour of effluent with 90-95 % efficiency. Tyagi *et al.* [49] studied the reducing efficiency for BOD, COD and lignin with 87.2, 94.7 and 97 % efficiency respectively. Rodriguez *et al.* [50] conducted a study for biodegradation of lignin with the use of some soil fungal sp. namely *Fusarium* oxysporum, *Penicillium chrysogenum*, *Fusarium solani* and reported 23.5, 27.4 and 22.6 %, respectively degradation efficiency for lignin whereas, only 25 % degradation efficiency for lignin has been indicated with *Chrysonilia sitophila* fungi. Abd El-rahim and Zaki [51] studied the reduction of colour upto 99 % with the application of fungi *Tinctoria borbonica*. *Schizophyllum commune* fungal specie has been found capable of reducing colour upto 90 %, BOD upto 70 % and COD upto 72 % within 2 days as reported by Saritha *et al.* [44]. *Glicladium virens* fungi has been employed to carry out bioremediation of paper-pulp effluent by reducing colour upto 42 %, lignin upto 52 % and BOD upto 65 %, studied by Khodaparast and Kamali [2]. Aftab *et al.* [52] studied the ability of *Coriolus versicolor* fungi in liquid culture for colour reduction of effluent with 60 % efficiency within 6 days incubation. Anand and Jha [53] studied the potential of *Aspergillus flavus* fungi for the bio-treatment of mill effluent and revealed colour reduction upto 31-51 % and lignin degradation upto 39-61 % within 10 days. Two other fungal sp. namely *Dardaleopsis* sp. and *P. chrysosporium* has been reported with COD reducing efficiency of 59.71 and 66-83 % respectively whereas, colour reducing efficiency of 86 % has been notified by both of them [54]. Fungi *Cryptococcus* has been notified with 35-40 % efficiency for lignin degradation and 50-53 % efficiency for colour reduction at pH = 5-6, as reported by Singhal and Thakur [47]. One other fungi *Datronia* has been recorded for decolourization with 89.8-90 % efficiency and COD reduction with 34.5-40.4 % efficiency, as reported by Torpong *et al.* [55]. Apiwatanapiwat *et al.* [56] examined three fungal species namely *Trichaptum, Datronia* and *Trametes* for the colour reduction of effluent with 54.4, 54.9 and 53.7 % efficiency, respectively.

Fungal treatment of paper pulp industry effluent has been found to be less feasible because fungal sp. are unable to grow rapidly under extreme conditions of high pH, temperature and limited oxygen.

Bacterial treatment: In order to obtain effective treatment of waste effluent, thereby reducing COD/BOD, lignin and colour some bacterial strains have also been isolated by some researchers. Chandra *et al.* [57] demonstrated two bacterial strains namely-*Bacillus cereus* and *Serratia marcescens* for their study. Colour reduction, lignin, BOD, COD reduction has been found to be 45-52, 30-42, 40-70 and 50-60 %, respectively in period of 7 days with the use of these strains. Raj *et al*. [58] studied *Bacillus* bacterial sp. for the treatment strategy. With the application of *Bacillus*, the result has been found to be 61 % for colour reduction, 53 % for lignin, 82 % for BOD and 78 % for COD removal in period of 6 days. One another researcher reported the bacterial strain *Aeromonas formicans* for the reduction of colour, COD and lignin. The reduction efficiency has been found to be 70-80 % for COD and lignin, 85 % for colour reduction in 8 days period as reported by Gupta *et al*. [59]. Bhatia *et al.* [60] examined the applicability of sulphate reducing bacteria with 70-75 % COD removal within 3 weeks period.

Combined applicability of fungus and bacteria has been studied by some researchers in order to increase the rate of degradation. Chuphal *et al*. [61] investigated the use of fungi followed by bacteria for the treatment strategy. The fungal treated effluents following the bacterial treatment using *Paecilomyces sp., Pseudomonas syringae pv. Myricae* shows the capability of degradation with 88.5 % colour, 79.5 % lignin, 87.2 % COD, 87.7 % phenol. Ghoreishi and Haghighi [12] studied the chemical and biological reactions to carry out degradation process and reported reduction of BOD with 99 %, COD reduction with 92 % and TSS reduction with 97 % in 6 days period. Marihal *et al*. [62] explored the application of *Rhizobacteria* isolated from tolerant crop sp. to carry out process of degradation of penta-chlorophenol with 90 % phenol reduction efficiency. Saraswathi and Saseetharan *et al*. [35] also examined the combination of different bacterial strains in order to increase the removal efficiency. He tried *Pseudomonas Alkaligenes, Bacillus pumilus* and *Bacillus subtilis* and proved to be more effective for degradation process with 92, 77 and 85 % BOD reduction, 77, 69 and 72 % COD reduction respectively. When used in combination, like *Pseudomonas alkaligenes* + *Bacillus subtilis* shows 98 and 77 % reduction of BOD and COD respectively while, other combination of *Pseudomonas alkaligenes* + *Bacillus subtilis* + *Bacillus pumilus* shows 79 and 69 % BOD and COD reduction respectively [35]. Biodegradation experiment has been carried out for the removal of pollutants by using *Cronobacter* heterotrophic bacterial sp. with degradation efficiency of 72.3 % for COD, 91 % for BOD and 55 % for the colour, as reported by Kumar *et al*. [63]. Other three bacterial species namely *Paenibacillus sp., Aneurinibacillus aneurinilyticus* and *Bacillus sp.* have been demonstrated by Chandra *et al.* [64] for the degradation of Kraft lignin. With the application of these strains the degradation of colour has been reported with the efficiency of 43, 56 and 65 %, respectively at pH-7-6 for 6 days. Singh *et al.* [65] investigated the mixed culture of two bacterial strains namely Bacillus and *Serrantia marcescens*, along with the addition of glucose and peptone and showed 90 % COD reduction in 7 days. Some other bacterial strains namely, *Pseudomonas, Bacillus, Pannonibacter* and *Ochrobacterium* has been examined for reducing COD from mill effluent reporting 85-86.5 % efficiency at operating conditions of 200 rpm and pH = 6.8 [66]. Abd El-Rahim & Zaki [51] and Murugesan [67] carry out the degradation of discharged black liquor from paper-pulp mill by two bacterial strains namely *Pseudomonas putida and Acienetobacter calcoaceticus* and indicated the 70-80 % COD and lignin degradation whereas, 80 % of colour reduction. Some other isolated bacterial strains namely *Pseudomonas putida, Citrobacter* spp. and *Enterobacter* spp. has been demonstrated for the biodegradation strategy and it has been found to have COD reduction with 96.80 %, colour reduction with 97 %, BOD reduction with 96.65 % and phenol reduction with 96.92 % within 24 h of growth [46,68]. *Paenibacillus* sp. one of the bacteria has been demonstrated for the treatment strategy and found to carry colour, COD/BOD and lignin degradation with 68, 78, 83 and 54 %, respectively at operating conditions of 120 rpm, 34 °C within 144 h [69]. Singh and Thakur [70] has reported two step treatment of effluent followed by micro-organisms. The anaerobically treatment with *Paecilomyces sp.* fungi and *Microbrevis luteum* bacterial strain reduces 70 % colour, 25 % lignin, 42 % COD, 39 % phenol in 15 days. This anaerobically treated effluent was further treated with micro-organism aerobically. The bacterial strain *Microbravis luteum* reduces 76 % colour, 69 % lignin, 75 % COD, 93 % phenol by third day [70]. The decolourization of effluent has also been examined with *Autochthonous* bacteria with 76 % reducing efficiency, as reported by Tiku *et al.* [46]. Tyagi *et al.* [49] also reported two bacterial strains *Bacillus subtilis, Micrococcus* *luteus* for the reduction of BOD/COD and lignin with 87.2, 94.7 and 97 % respectively. Ramsay and Nguyen [71] reported the 26-54 % colour reduction of effluent with *Pseudomonas aeruginosa* bacteria aerobically. Patricia Oliveira *et al.* [72] studied the capability of *Bacillus pumilus* and *Paenibacillus* sp. for the colour and COD reduction. The colour reducing efficiency of 41.87 and 42.30 % respectively whereas, 22 % COD reduction has been achieved by both species at pH = 9 with 24 h.

Algal treatment: In order to carry out treatment process biologically some researchers have tried few algal species for the treatment of paper-pulp mill effluent. Iyovo *et al.* [73] and Sharma *et al.* [74] reported the algae *Microcystis spp.* to carry out decolourization of Kraft mill effluent with 70 % colour reduction in about 2 month time period. Sharma *et al.* [74] and Chandra *et al.* [75] reported the colour reduction of mill effluent with 80 % efficiency by the application of mixed culture of three algae namely *Chlorella* + *Chlamydomonas* + *Microcystis* sp. in 30 days. Table-1 illustrates the percentage removal of various contaminants of industrial effluent by using different treatment strategies.

Conclusion

The following conclusions have been revealed from the study:

• Maximum removal efficiency for BOD in pulp and paper effluent has been monitored with fungal treatment using *Trichoderma reesei sp*. *i.e.* upto 99 % removal efficiency.

TABLE-1
THE PERCENTAGE REMOVAL OF VARIOUS CONTAMINANTS OF INDUSTRIAL EFFLUENT BY USING DIFFERENT TREATMENT STRATEGIES

Treatment strategy/microbe	Treatment strategy	COD (%)	BOD (%)	Colour (%)	Phenol (%)	Lignin (%)	Operating parameters	Ref.
Activated sludge	Aerobic	95						[15]
Activated sludge	Aerobic	70	90					[16-18]
Aerated lagoon	Aerobic	30-40	50-70					[10-12]
Aerated lagoon	Aerobic	67						[13]
UASB reactor	Anaerobic	66						[21]
UASB reactor	Anaerobic	80-93						[22]
UASB reactor	Anaerobic	79-82						[23]
UASB reactor	Anaerobic	82 92 86					35 °C 55 °C 65 °C	[24]
UAF reactor	Anaerobic	50	70					[25]
Soyabean peroxidise-enzymatic	Enzyme				97		56 °C	[30]
Plant peroxidise from potato pulp	Enzyme				90		2 h	[31]
Bacillus cereus	Bacteria	50-60	40-70	45-52		30-42	7 days	[36]
Serratia marcescens	Bacteria	50-60	40-70	45-52		30-42	7 days	[36]
Bacillus sp.	Bacteria	78	82	61		53	6 days	[37]
Aeromonas formicans	Bacteria	70-80				85	8 days	[38]
Sulphate reducing bacteria	Bacteria	70-75					3 weeks	[39]
Rhizobacteria	Bacteria				90			[42]
Paenibacillus sp.	Bacteria			43		30	6 days pH-7.6	[49]
Aneurinibacillus aneurinilyticus	Bacteria			56		33	6 days pH-7.6	[49]
Bacillus sp.	Bacteria			65		37	6 days pH-7.6	[49]
Cronobacter sp.	Heterotrophic bacteria	–	91				16-18 h	[48]
Pseudomonas alkaligenes	Bacteria	77	92					[35]
Bacillus pumilus	Bacteria	69	79					[35]
Bacillus subtilis	Bacteria	72	85					[35]
(Pseudomonas Alkaligenes + Bacillus subtilis) combination	Bacteria	77	98					[35]
(*Pseudomonas alkaligenes + Bacillus subtilis + Bacillus pumilus*) combination	Bacteria	69	79					[35]
Paecilomyces sp.	Bacteria	87		88.5	87.8	79.5		[45]
Pseudomonas syringae	Bacteria	87		88.5	87.8	79.5		[45]
Bacillus and *Serrantia marcescens*	Bacteria				94			[65]
Pseudomonas, Bacillus, Pannonibacter and *Ochrobacterium*	Bacteria	85-86.5					35 °C, pH = 6.8, 200 rpm	[66]
Pseudomonas putida, Acienetobacter calcoaceticus	Bacteria	70-80		80		70-80	8 days	[51,67]
Pseudomonas putida, Citrobacter spp. and *Enterobacter*	Bacteria	96.80	96.63	97	96.62		24 h	[46,68]

Paenibacillus	Bacteria	78	83	68		54	144 h, 34 °C, 120 rpm	[69]
Autochthonou	Bacteria			76				[46]
Bacillus subtilis, Micrococcus luteus	Bacteria	94.7	87.2			97	9 days	[49]
Pseudomonas aeruginosa	Bacteria			26-54				[71]
Bacillus pumilus	Bacteria	22		41.87			pH = 9, 24 h	[72]
Paenibacillus	Bacteria	22		42.30			pH = 9, 24 h	[72]
Candida tropicalis	Fungi				98.7			[32]
White rot fungi	Fungi	41		34		16		[36]
T. versicolor	Fungi	78		94				[37]
P.chrysosporium	Fungi	79		84				[37]
Rhizopus oryzae	Fungi	50		92-95			24 h 25-45 °C, pH 3-5	[33]
Trichoderma reesei	Fungi	80	99					[35]
Fomes lividus	Fungi	59..3		59.3			7th day	[34]
Trametes versicolor	Fungi	59.3		68			6th day	[34]
Trametes pubescens	Fungi				94.65 (2-chloro phenol) 67.8 (pentachloro phenol)			[38]
Emericella nidulans	Fungi			66.6		37		[39]
Aspergillus niger	Fungi	60		43				[40]
Rhizopus oryzae	Fungi	82						[41]
Phanerochaete chrysosporium	Fungi	81						[41]
Fusarium sambucinum	Fungi	89.4		78.6		79		[42]
White rot and soft rot	Fungi	74-81					10 days	[41]
Cellobiose dehydrogenate	Fungi			50			4 days	[43]
Schizophyllum commune	Fungi	72	70				2 days, pH=4-5	[2,44]
Phaerochaete chrysosporium,	Fungi	89.4		78.6		79	21 days	[45]
Trametes hirsute *Tinctoria borbonica*	Fungi	25		85			3 days, pH = 4	[2,46]
Gliocladium virens	Fungi		65	42		52		[2]
Coriolus versicolor	Fungi			60			6 days	[46]
Cryptococcus	Fungi			27		24	5th day	[47]
Aspergillus foetidus	Fungi			90-95				[48]
Phanerochaete	Fungi	94.7	87.2			97	9 days	[49]
Fusarium oxysporum	Fungi					23.5		[50]
Penicilllium chrysogenum	Fungi					27.4		[50]
Fusarium solani	Fungi					22.6		[50]
Chrysonilia sitophila	Fungi					25	3 months	[50]
Tinctoria borbonica	Fungi			90-99				[51]
Schizophyllum commune	Fungi	72	70	90			2 days	[44]
Glicladium virens	Fungi		65	42		52		[2]
Coriolus versicolor	Fungi			60			6 days	[52]
Aspergillus flavus	Fungi			31-51		39-61	10 days	[53]
Dardaleopsis sp.	Fungi	59.71		86				[54]
P.chrysosporium	Fungi	66.83		86				[54]
Cryptococcus	Fungi			50-53		35-40		[47]
Datronia	Fungi	34.5-40.4		89.8-90				[55]
Trichaptum	Fungi			54.4				[56]
Datronia	Fungi			54.9				[56]
Trametes	Fungi			53.7				[56]
Microcystis	Algae			70			2 month	[73]
Chlorella + Chlamydomonas + Microcystis	Algae			30			30 days	[74,75]

• Maximum removal efficiency for COD has been reported by *Pseudomonas putida, Citrobacter spp. and Enterobacter* reporting 96.80 % removal efficiency.

• Maximum colour degradation has been noticed with fungal treatment using *Tinctoria borbonica i.e.* 90-99 % degradation efficiency in the paper-pulp effluent.

• Whereas, maximum removal of phenol has been noticed with fungal treatment with 98.7 % efficiency using *Candida tropicalis sp*.

• Lignin degradation has been found maximum with the bacterial treatment with 97 % efficiency using *Bacillus subtilis, Micrococcus luteus* and with the application of *Phanerochaete* fungi with 97 % reducing efficiency.

It is further concluded that not even a single treatment strategy can be effectively used for the removal of all the contaminants of paper and pulp effluent but combination of two or more treatment strategies are required in combination for their removal. Still the research is going on in this sector to develop such a strategy which is low-cost, eco-friendly and less time consuming that is able to treat paper pulp effluent effectively and bring down undesired wastewater parameters within permissible limits of discharge.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES

1. S. Mohammadi, A. Kargari, H. Sanaeepur, K. Abbassian, A. Najafi and E. Mofarrah, *Desalination Water Treat.*, **53**, 2215 (2015); https://doi.org/10.1080/19443994.2014.883327.
2. M. Kamali and Z. Khodaparast, *Ecotoxicol. Environ. Saf.*, **114**, 326 (2015); https://doi.org/10.1016/j.ecoenv.2014.05.005.
3. P. Bajpai, A. Mehna and P.K. Bajpai, *Process Biochem.*, **28**, 377 (1993); https://doi.org/10.1016/0032-9592(93)80024-B.
4. R. Ragunathan and K. Swaminathan, *World J. Microbiol. Biotechnol.*, **20**, 389 (2004); https://doi.org/10.1023/B:WIBI.0000033064.63031.1c.
5. M.R. Assalin, E.S. Almeida and N. Durán, *Int. J. Environ. Res. Public Health*, **6**, 1145 (2009); https://doi.org/10.3390/ijerph6031145.
6. K.S. Rajesh, I.M. Singarave, P.S. Sankaralingam, S. Subramanian and S.V. Subrahmanyam, *IPPTA J.*, **21**, 1 (2009).
7. O. Ashrafi, L. Yerushalmi and F. Haghighat, *Int. J. Greenh. Gas Control*, **17**, 462 (2013); https://doi.org/10.1016/j.ijggc.2013.06.006.
8. G. Thompson and C. Forster, *Water Res.*, **37**, 2636 (2003); https://doi.org/10.1016/S0043-1354(03)00076-9.
9. P.O. Persson, Cleaner Production: Strategies & Technology for Environmental Production, Stockholm, Royal Institute of Technology Industrial Ecology (2011).
10. J.D. Achoka, *Water Res.*, **36**, 1203 (2002); https://doi.org/10.1016/S0043-1354(01)00325-6.
11. T. Mahmood and M. Paice, *J. Environ. Eng. Sci.*, **5**, 383 (2006); https://doi.org/10.1139/s05-047.
12. S.M. Ghoreishi and M.R. Haghighi, *Chem. Eng. J.*, **127**, 59 (2007); https://doi.org/10.1016/j.cej.2006.09.022.
13. C.W. Bryant, *Water Sci. Technol.*, **62**, 1248 (2010); https://doi.org/10.2166/wst.2010.934.
14. G. Thompson, J. Swain, M. Kay and C.F. Forster, *Bioresour. Technol.*, **77**, 275 (2001); https://doi.org/10.1016/S0960-8524(00)00060-2.
15. S. Bengtsson, A. Werker, M. Christensson and T. Welander, *Bioresour. Technol.*, **99**, 509 (2008); https://doi.org/10.1016/j.biortech.2007.01.020.
16. M. Lerner, N. Stahl and N.I. Galil, Comparative Study of MBR and Activated Sludge in the Treatment of Paper Mill Wastewater, In: Forest Industry Wastewaters VIII. IWA Publishing, London, United Kingdom, pp. 23-29 (2007).
17. T. Mahmood and A. Elliott, *J. Environ. Eng.*, **132**, 1019 (2006); https://doi.org/10.1061/(ASCE)0733-9372(2006)132:9(1019).
18. P. Norris, R. Marshall and M. Richard, High Temperature Effects on Activated Aludge Treatment Performance and Sludge Quality in a Recycle Mill. In: Proceedings of the 2000 TAPPI International Environmental Conference and Exhibition Technical Association of the Pulp and Paper Industry Press, Denver, USA, pp. 383-406 (2000).
19. Ochre-media, Wastewater Treatment Solutions in Pulp and Paper Industry, Andhra Pradesh (India): Ochre Media Pvt. Ltd (2001).
20. J. Lelieveld, S. Lechtenbohmer, S.S. Assonov, C.A.M. Brenninkmeijer, C. Dienst, M. Fischedick and T. Hanke, *Nature*, **434**, 841 (2005); https://doi.org/10.1038/434841a.
21. W. Chen and N.J. Horan, *Environ. Technol.*, **19**, 153 (1998); https://doi.org/10.1080/09593331908616667.
22. S. Chinnaraj and G. Venkoba Rao, *Biomass Bioenergy*, **30**, 273 (2006); https://doi.org/10.1016/j.biombioe.2005.10.007.
23. A.P. Buzzini and E.C. Pires, *Bioresour. Technol.*, **98**, 1838 (2007); https://doi.org/10.1016/j.biortech.2006.06.030.
24. J.A. Rintala and S. Lepisto, *Water Res.*, **26**, 1297 (1992); https://doi.org/10.1016/0043-1354(92)90124-M.
25. N.S. Deshmukh, K.L. Lapsiya, D.V. Savant, S.A. Chiplonkar, T.Y. Yeole, P.K. Dhakephalkar and D.R. Ranade, *Chemosphere*, **75**, 1179 (2009); https://doi.org/10.1016/j.chemosphere.2009.02.042.
26. D.Y. Xu and Z. Yang, *Chemosphere*, **92**, 391 (2013); https://doi.org/10.1016/j.chemosphere.2012.12.076.
27. S. Mukherjee, B. Basak, B. Bhunia, A. Dey and B. Mondal, *Rev. Environ. Sci. Biol.*, **12**, 61 (2013); https://doi.org/10.1007/s11157-012-9302-y.
28. S. Ba, A. Arsenault, T. Hassani, J.P. Jones and H. Cabana, *Crit. Rev. Biotechnol.*, **33**, 404 (2013); https://doi.org/10.3109/07388551.2012.725390.
29. A. Steevensz, S. Madur, W. Feng, K.E. Taylor, J.K. Bewtra and N. Biswas, *Enzyme Microb. Technol.*, **55**, 65 (2014); https://doi.org/10.1016/j.enzmictec.2013.12.005.
30. F. Rezvani, H. Azargoshasb, O. Jamialahmadi, S. Hashemi-Najafabadi, S.M. Mousavi and S.A. Shojaosadati, *Biochem. Eng. J.*, **101**, 32 (2015); https://doi.org/10.1016/j.bej.2015.04.019.
31. K. Kurnik, K. Treder, M. Skorupa-Klaput, A. Tretyn and J. Tyburski, *Water Air Soil Pollut.*, **226**, 254 (2015); https://doi.org/10.1007/s11270-015-2517-0.
32. S. Kumar, Neeraj, V.K. Mishra and SK. Karn, *Afr. J. Biotechnol.*, **17**, 57 (2018); https://doi.org/10.5897/AJB2017.15906.
33. R. Nagarathnamma and P. Bajpai, *Appl. Environ. Microbiol.*, **65**, 1078 (1999).
34. K. Selvam, K. Swaminathan, M. Hoon Song and K.-S. Chae, *World J. Microbiol. Biotechnol.*, **18**, 523 (2002); https://doi.org/10.1023/A:1016370110697.
35. R. Saraswathi and M.K. Saseetharan, *J. Water Resource Prot.*, **2**, 660 (2010); https://doi.org/10.4236/jwarp.2010.27076.
36. N. Saxena and R.K. Gupta, *Indian J. Exp. Biol.*, **36**, 1049 (1998).
37. G.K. Prasad and R.K. Gupta, *Indian J. Environ. Health*, **39**, 89 (1997).
38. L.F. González, V. Sarria and O.F. Sánchez, *Bioresour. Technol.*, **101**, 3493 (2010); https://doi.org/10.1016/j.biortech.2009.12.130.
39. A. Singhal and I.S. Thakur, *Biochem. Eng. J.*, **46**, 21 (2009); https://doi.org/10.1016/j.bej.2009.04.007.
40. T. Liu, H. Hu, Z. He and Y. Ni, *Bioresour. Technol.*, **102**, 7361 (2011); https://doi.org/10.1016/j.biortech.2011.04.043.
41. A.C. Freitas, F. Ferreira, A.M. Costa, R. Pereira, S.C. Antunes, F. Goncalves, T.A.P. Rocha-Santos, M.S. Diniz, L. Castro, I. Peres and A.C. Duarte, *Sci. Total Environ.*, **407**, 3282 (2009); https://doi.org/10.1016/j.scitotenv.2009.01.054.

42. P. Malaviya and V.S. Rathore, *Bioresour. Technol.*, **98**, 3647 (2007); https://doi.org/10.1016/j.biortech.2006.11.021.
43. K.G. Wingate, T. Stuthridge and S.D. Mansfield, *Biotechnol. Bioeng.*, **90**, 95 (2005); https://doi.org/10.1002/bit.20419.
44. S.Senthilkumar, M. Perumalsamy and H.J. Prabhu, *J. Saudi Chem. Soc.*, **18**, 845 (2014); https://doi.org/10.1016/j.jscs.2011.10.010.
45. V. Saritha, Y.A. Maruthi and K. Mukkanti, *BioResources*, **5**, 8 (2010).
46. D.K. Tiku, A. Kumar, R. Chaturvedi, S.D. Makhijani, A. Manoharan and R. Kumar, *Int. Biodeterior. Biodegrad.*, **64**, 173 (2010); https://doi.org/10.1016/j.ibiod.2010.01.001.
47. A. Singhal and I.S. Thakur, *Biochem. Eng. J.*, **46**, 21 (2009); https://doi.org/10.1016/j.bej.2009.04.007.
48. S. Sumathi and V. Phatak, *Environ. Technol.*, **20**, 93 (2000); https://doi.org/10.1080/09593332008616797.
49. S. Tyagi, V. Kumar, J. Singh, P. Teotia, S. Bisht and S. Sharma, *Int. J. Environ. Res.*, **8**, 561 (2014).
50. J. Rodriguez, A. Ferraz, R.F.P. Nogueira, I. Ferrer, E. Esposito and N. Duran, *Appl. Biochem. Biotechnol.*, **62**, 233 (1997); https://doi.org/10.1007/BF02787999.
51. W.M. Abd El-Rahim and E.A. Zaki, *Arab J. Biotechnol.*, **8**, 189 (2005).
52. U. Aftab, M.R. Khan, M. Mahfooz, M. Ali, S.H. Aslam and A. Rehman, *Pak. J. Zool.*, **43**, 1 (2011).
53. B. Anand and H. Jha, *Int. J. Curr. Microbiol. Appl. Sci.*, **5**, 19 (2016).
54. S. Prasongsuk, P. Lotrakul, T. Imai and H. Punnapayak, *Sci. Asia*, **35**, 37 (2009); https://doi.org/10.2306/scienceasia1513-1874.2009.35.037.
55. T. Kreetachat, O. Chaisan and P. Vaithanomsat, *Int. J. Environ. Sci. Develop.*, **7**, 321 (2016).
56. W. Apiwatanapiwat, P. Siriacha and P. Vaithanomsat, *Kasetsart J.: Nat. Sci.*, **40**, 215 (2006).
57. R. Chandra, A. Raj, S. Yadav and D.K. Patel, *Environ. Monit. Assess.*, **155**, 1 (2009); https://doi.org/10.1007/s10661-008-0413-4.
58. A. Raj, M.M. Reddy, R. Chandra, H.J. Purohit and A. Kapley, *Biodegradation*, **18**, 783 (2007); https://doi.org/10.1007/s10532-007-9107-9.
59. V.K. Gupta, A.K. Minocha and N. Jain, *J. Chem. Technol. Biotechnol.*, **76**, 547 (2001); https://doi.org/10.1002/jctb.417.
60. S.P. Bhatia, D. McGinty, C.S. Letizia and A.M. Api, *Toxicol. Environ. Chem.*, **46**, 197 (2008); https://doi.org/10.1016/j.fct.2008.06.071.
61. Y. Chuphal, V. Kumar and I.S. Thakur, *World J. Microbiol. Biotechnol.*, **21**, 1439 (2005); https://doi.org/10.1007/s11274-005-6562-5.
62. A.K. Marihal, K.S. Jagadeesh, S. Sinha, *Int. J. Environ. Sci. Eng.*, **1**, 189 (2009).
63. V. Kumar, P. Dhall, S. Naithani, A. Kumar and R. Kumar, *J. Bioremediat. Biodegrad.*, **5**, 218 (2014); https://doi.org/10.4172/2155-6199.1000218.
64. R. Chandra, A. Raj, H.J. Purohit and A. Kapley, *Chemosphere*, **67**, 839 (2007); https://doi.org/10.1016/j.chemosphere.2006.10.011.
65. S. Singh, R. Chandra, D.K. Patel, M.M.K. Reddy and V. Rai, *Bioresour. Technol.*, **99**, 5703 (2008); https://doi.org/10.1016/j.biortech.2007.10.022.
66. V. Kumar, P. Dhall, R. Kumar, Y.P. Singh and A. Kumar, *Sci. World J.*, **Article ID 127014** (2012); https://doi.org/10.1100/2012/127014.
67. K. Murugesan, *Indian J. Exp. Biol.*, **41**, 1239 (2003).
68. H. Keharia and D. Madamwar, *Indian J. Exp. Biol.*, **41**, 1068 (2003).
69. A. Raj, S. Kumar, I. Haq and S.K. Singh, *Ecol. Eng.*, **71**, 355 (2014); https://doi.org/10.1016/j.ecoleng.2014.07.002.
70. P. Singh and I.S. Thakur,, *Bioresour. Technol.*, **97**, 218 (2006); https://doi.org/10.1016/j.biortech.2005.02.022.
71. J.A. Ramsay and T. Nguyen, *Biotechnol. Lett.*, **24**, 1757 (2002); https://doi.org/10.1023/A:1020644817514.
72. P.L. Oliveira, M.C.T. Duarte, A.N. Ponezi and L.R. Durrant, *Braz. J. Microbiol.*, **40**, 354 (2009); https://doi.org/10.1590/S1517-83822009000200027.
73. G.D. Iyovo, G. Du and J. Chen, *J. Microb. Biochem. Technol.*, **2**, 100 (2010); https://doi.org/10.4172/1948-5948.1000032.
74. R. Sharma, S. Chandra, A. Singh and K. Singh, *IIOAB J.*, **5**, 6 (2014).
75. R. Chandra, R. Singh and S. Yadav, *J. Chem. Technol. Biotechnol.*, **87**, 436 (2012); https://doi.org/10.1002/jctb.2758.