Textiles

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ABSTRACT: A review of the literature published in 2009 on topics relating to the treatment alternatives for wastewater from the textile industries is presented. This review is divided into the following sections: a brief introduction on the implementation of the Best Available Techniques into textile industry, a review of the more promising treatment technologies distinguished into physico-chemical, biological and combined processes.

KEYWORDS: biological process, combined process, physico-chemical process, reuse.

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Introduction

A large scale textile mill was selected as a pilot plant for the implementation of the Best Available Techniques, BAT, Reference (BREF) Textile Document under the European Union's Integrated Pollution Prevention and Control (IPPC) Directive.

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The results of the study clearly indicated that the application of BAT measures is essential to reduce water and energy consumption (Koacabas et al., 2009). A chemical substitution study was conducted by Ozturk et al. (2009) on one of the major textile factories in Turkey with a capacity of 20 000 tons of denim fabric per year. Chemical consumption level, receipts applied, environmentally problematic and alternative chemicals were examined. IPPC and BAT for the textile industry were accepted as main reference document. According to this study, over 70% reduction in sulphide, which is very toxic to aquatic life, was achieved by replacing sulphur dyestuff with low sulphide content. By replacing an alternative complexing agent, the mill reduced the Chemical Oxygen Demand (COD) load and increased the biodegradable content to the wastewater treatment plant.

Physico-Chemical Processes

Photodegradation. Ghezzar et al. (2009) studied the degradation of two polluted textile wastewaters (WW1 and WW2) from SOITEX (silk and textile) industry using the plasma-catalytic process, by non thermal Gliding arc technique coupled to Degussa P25 titanium dioxide (TiO_2) as photo-catalyst. The results showed that maximum degradation was attained for 3 g/L TiO_2 concentration. For WW1, degradation was 95% at the end of 60 min of

treatment time. The same wastewater was completely decolourised after only 30 min of plasma-catalytic treatment time. A novel structure TiO_2/Ti film was prepared by Hua et al. (2009) on a titanium matrix using anodic oxidation technique and applied to degrade Reactive Brilliant Red (RBR) dye in simulative textile effluents. The results showed that the surface morphology of the film was coral structure and the crystal structure of the film was atanase. The color and COD removal efficiencies of RBR achieved 73% and 60% in 1h, respectively. A numerical finite volume model for simulation of decolorization and mineralization of dyes by nanophotocatalysis using immobilized titania was presented by Mahmoodi and Arami (2009a). Three textile dyes, Remazol Red RB (RR), Remazol Brilliant Blue (RBB) and Cibacron Blue TGRE (CB) were used as model compounds. The results showed that the dyes were decolorized and mineralized. A close agreement was obtained between model prediction and experimental results. The same authors (Mahmoodi and Arami, 2009b) demonstrated feasibility and performance of photocatalytic degradation and toxicity reduction of textile dye Acid Blue 25 at a pilot scale in an immobilized titania nanoparticle photocatalytic reactor. Mineralization of the dye was achieved with the production of nitrate and sulfate anions.

Paschoal et al. (2009) obtained 52.6-69.0% COD reduction, 80-90% of discoloration of disperse dyes and 46.8-49.8% Total Organic Carbon (TOC) removal by photoelectrocatalytic oxidation. The process utilized titanium dioxide thin-film electrodes prepared by the sol-gel method as a photo-oxidative anode. Zayani et al. (2009) investigated performances of a solar photocatalytic pilot plant equipped with thin film fixed bed reactor and using TiO_2-P25 (Degussa) for the removal of commercial azo dye. The process showed to be most effective for an optimum amount of TiO_2 (10 g/m^2), flow rate (3 m^3/h) as well as initial TOC (30 mg/L) value.

Two photocalysts based TiO_2-pillared intercalated montmorillonite were prepared by microwave for 10 min at 700 W or by furnace heating at 673K. Montmorillonite pillaring with TiO_2 increased the basal spacing to 14.7 Å (conventional heating) and 17.6 Å (microwave heating). At pH=5.8, the maximum adsorption capacity of Solophenyl Red 3BL (a textile azo dye) on the TiO_2-pillared montmorillonite calcined by microwave was 185 mg/g, whereas it was 1.4 and 3 fold lower on the TiO_2-pillared montmorillonite calcined at 673K, and on the Degussa TiO_2 P25, respectively (Damardji et al., 2009a). The same authors (Damardji et al., 2009b) also carried out experiments on photodegradation with the same catalyst in an aqueous solution with Solophenyl Red 3BL concentration of 100 mg/L, at different pH values and photocatalyst contents (400-5000 mg/L). The lower the pH, the higher the dye photodegradation rate constants: 0.0966 and 0.0006 1/min, obtained at pH=2.5 and pH=11, respectively. This was in agreement with a higher adsorption of the dye on the catalyst at acidic rather than at basic pH.

A thin-film photoelectrocatalytic (PEC) reactor with slant-placed TiO_2/Ti anode was developed and successfully applied by Xu et al. (2009) to degrade Rhodamine B (RhB) and textile effluent. Using a 5-150

mg/L RhB solution as the model system, thin-film OEC removed total color and TOC by 99-28% and 78-15%, respectively, in 1h, which was much higher than 82-7% and 60% to zero by conventional PEC. The enhanced treatment efficiency was attributed to the significantly reduced path length of irradiation light source. The influence of several factors in the simultaneous photocatalytic degradation of three textile dyes (Acid Red 97, Acid Orange 61 and Acid Brown 425) was studied by Fernández et al. (2009) using a fractional factorial design 2^{5-1}. A rapid analytical methodology was developed which enabled the three dyes to be quantified simultaneously despite the overlap of their spectra. The kinetic constant of degradation for each dye in all the experiments was evaluated.

Advanced Oxidation Process. A novel Fenton-like system, employing Zero Valent Iron (ZVI) and air bubbling, was developed by Zhou et al. (2009), to treat a simulated textile wastewater containing azo dye Reactive Black 5 (RB5) and Ethylenediaminetetraacetic acid (EDTA). After 3h reaction, the removal rates of RB5, EDTA, TOC and COD were 100%, 96.5%, 68.6% and 92.2%, respectively. It was also demonstrated that ultrasound presented significant synergistic effect on the degradation and mineralization of both RB5 and EDTA.

Degradation of Remazol Brilliant Blue R (RBBR) (anthraquinone dye) and Acid Black 1 (AB1) (azo dye) by Fenton oxidation and low-cost Fe^0/air process was compared by Chang et al. (2009). The Fe^0/air process rapidly decolorized dyes within 5 min at the Fe^0 doses of 10 and 50 g/L for RBBR and AB1, respectively. COD removals of both dyes by the Fe^0/air process were significantly higher than those by Fenton oxidation. The toxicity of Fe^0/air-treated solution was significantly lower than that of Fenton-treated solution.

Arslan-Alaton et al. (2009) investigated treatability of synthetic azo dye production wastewaters from Acid Blue 193 (AB193) and Reactive Black 39 (RB39) production and real Reactive Black 39 (rRB39) production effluent via Photo-Fenton-like process. Response Surface Methodology (RSM) was employed to assess the individual and interactive effects of several critical process parameters on decolorization and COD and TOC abatement rates and to optimize the Photo-Fenton-like process.

Reactive Red 194 (RR194). Reactive Yellow 145 (RY145) azo dyes and synthetic textile dye-bath effluent were treated by Gül and Özcan-Yildirim (2009) with O_3 and H_2O_2/UV-C processes. It was observed that while H_2O_2/UV-C process was more pH dependent in decolorization and dearomatization reactions, ozonation was less selective and more effective in both decolorization and dearomatization reactions. Comparing the O_3 and H_2O_2/UV-C processes, it was found that fastest color and highest TOC removal were obtained by ozonation at pH 11. Figueroa et al. (2009) demonstrated that it was possible to electroproduce a stoichiometric amount of Fenton's reagent for the oxidation of 0.061 mM Reactive Black 5 (in tap water + 0.05 M Na_2SO_4, at pH~2.8). Similar results were obtained for solutions containing 0.1 mM Acid Green 25.

Factors affecting the rate of COD of a synthetic waste solution containing water soluble direct dyes (Sirius Red F3B and Sirius Blue SBRR) by ozone gas were studied

by Turhan and Turgut (2009) using a batch bubble column. The authors showed that the COD of direct dyestuff wastewater was reduced by 58.9% for Sirius Red F3B and 60.9% for Sirius Blue SBRR after ozone bubbling treatment for 2h.

The kinetics of oxidation of three triphenylmethane dyes, namely p-rosaline, crystal violet and ethyl violet, by chloramines-T (CAT) in NaOH medium catalyzed by Pd(II)catalyst were studied by Vinod et al. (2009). Catalytic constants and the activation parameters with reference to catalyst were computed. Pd(II) catalyzed reactions were found to proceed nearly four times faster than the uncatalyzed reactions. According to Constapel et al. (2009), the liquid chromatography/mass spectrometry (LC-MS) was an appropriate mean of following the decolorization of wastewater from the textile industry by ozonation. Franchiang and Tseng (2009) investigated the degradation of anthraquinone reactive dye C.I. Reactive Blue 19 (RB19) with initial concentration of 100 mg/L in aqueous solution by ozone oxidation. The results obtained showed that the anthraquinone structures, nitrogen linkages and amino groups of RB19 were destroyed under direct ozone reaction. Detoxification and enhanced biodegradability was achieved with the ozone treatment. Germirli Babuna et al. (2009) also found detoxification and increased biodegradability of naphthalene sulphonic acid derivative commonly used in textile mills when applying ozonation. The experiments showed that application of 5325 mgO_3/h ozone for 30 min at original pH was the optimum condition.

Degradation and mineralization of the azo dye Congo Red in aqueous solution by ozone was studied by Khadhraoui et al. (2009). The authors concluded that ozone by itself was strong enough to decolorize the aqueous solution in the early stage of the oxidation process. Nonetheless, efficient mineralization was not achieved. The presence of MgO nanocrystal catalysts into the ozonation reactor greatly accelerated the rate of Reactive Red 198 (RR198) degradation, thereby reducing the reaction time and improving the reduction of color and COD compared to the conventional ozonation (Moussavi and Mahmoudi, 2009).

Electrochemical Process. Wang et al. (2009) investigated the anodic and indirect cathodic removals of color and COD from real dyeing wastewaters simultaneously using stacked Pt/Ti screen anode and a graphite packed-bed cathode in a divided flow-by-electrochemical reactor. The color and COD removal efficiencies in the anodic chamber were much higher than those in the cathodic chamber. The overall (anodic plus cathodic) removal efficiencies increased with the applied current density, the amount of NaCl added and the temperature. According to Santana et al. (2009), total discoloration of the commercial azo dye Reactive Orange 122 (RO122) was rapidly achieved in both acid and alkaline solutions, at a constant ozone application rate of 0.25 g/h. This result revealed that both direct (O_3) and indirect (HO•) oxidative pathways were efficient for color removal although an alkaline medium proved to be somewhat superior. Synthetic solutions of hydrolyzed Color Index (C.I.) Reactive Orange 4, a monoazo textile

dye commercially named Procion Orange MX-2R (PMX2R) and C.I. 18260, was exposed to electrochemical treatment under galvanostatic conditions and Na_2SO4 as electrolyte. Electro-oxidation degraded both the azo group and aromatic structures. The process followed pseudo-first order kinetics and decolourisation rates showed a considerable dependency on the applied current density (del Río et al., 2009a). The electrochemical treatment in a divided (oxidation and reduction processes) and an undivided cell (oxido-reduction process) was employed by the same authors (del Río et al., 2009b) to mineralize and decolourized the same monoazo dye PMX2R. Degradation of the dye was followed by TOC, Total Nitrogen (TN) and COD determinations. It was found that oxido-reduction process gave the best results in terms of COD removal where the intermediates generated presented a very high oxidation state. The oxidation process presented a more complex mechanism of decolourisation since a higher number of intermediates was generated.

The purification of textile wastewater by electrocoagulation and electrooxidation techniques was studied by Bhaskar Raju et al. (2009). The suspended solids (TSS) were removed to the extent of 97% from its initial concentration of 1565 mg/L by electrocoagulation. The initial COD of 530 mg/L was reduced to 246 mg/L using mild steel anode. After electrocoagulation, the effluent was further subjected to electrooxidation using different materials viz. graphite and $RuO_2/IrO_2/TaO_2$ coated titanium as anodes. The COD was removed to the extent of 90-93% using graphite and 54% using $RuO_2/IrO_2/TaO_2$ coated titanium. A two-compartment electrolytic cell, separated by an anion exchange membrane, was developed by Raghu et al. (2009) for color removal. In this new reactor, indirect oxidation anode, indirect oxidation by hydrogen peroxide and ultraviolet peroxide and ultraviolet/hydrogen peroxide (UV/H_2O_2) at cathode could occur simultaneously. Compared to the traditional one-cell reactor, the new reactor reduced the energy cost approximately by 25-40%.

According to Cho et al. (2009), simulated textile wastewater was degraded using a membraneless electrochemical reactor with immobilized peroxidase on the porous Celite. The decolorization efficiencies achieved using the electrochemical and electroenzymatic methods were 35% and 92%, respectively. Biodegradability, measured as the ratio of 5-day Biochemical Oxygen Demand (BOD_5) to COD, was enhanced by about 1.88 times when using the electroenzymatic treatment rather than raw wastewater, which could not be achieved using the electrochemical treatment.

Coagulation-Flocculation. Aragonés-Beltrán et al. (2009) applied the multicriteria decision analysis (MCDA) to help the selection of the coagulant and its concentration in the physical-chemical wastewater treatment of textile wastewater. Two well known MCDA techniques were used: analytical hierarchic process (AHP) and preference ranking organization method for enrichment evaluations (PROMETHEEs) and the results obtained compared. Anouzla et al. (2009) demonstrated the applicability of the steel industrial wastewater (SIWW) $FeCl_3$ rich as an effective coagulant for Disperse Blue 79 (DB79) solution removal.

A full factorial central composite design was used for determining the optimum process conditions leading to the maximum percentage removal of DB79.

Synthesis of cationic tamarind kernel polysaccarhide (Cat TKP), its detailed physicochemical characteristics and application as an efficient focculant for the treatment of textile industry wastewater was investigated by Pal et al. (2009). *N*-3-Chloro-2-hydroxypropyl trimethyl ammonium chloride (CHPTAC) was used as a cationic reagent to introduce quaternary amine groups onto the backbone of tamarind kernel polysaccarhide (TKP). The flocculation experiments showed that TKP alone contributed little to the flocculation. However, cationic TKP led to significant improvement as flocculant for the treatment of the textile industry wastewater.

Removal of Reactive Yellow 3 (RY3) using indirect electrochemical oxidation method was successfully performed by Maljaei et al. (2009). Comparing the rates of dye removal under different conditions, the influence of pH of the solution was more significant and pronounced.

Membrane. Nanofiltration (NF) and reverse osmosis (RO) thin film composite polyamide modules were demonstrated by Nataraj et al. (2009) to be very effective in removing color in simulated wastewater. The experimental results showed that increasing the dye concentration from 100 to 500 and to 1000 mg/L resulted in a decrease of salt rejection at all operating pressures. Two kinds of NF membranes were investigated by Han et al. (2009) in treating the Sulfur Black B (SBB) dye wastewater. Negatively charged polypiperazine amide/poly(phthalazinone ether sulfone ketone) (PIP/PPESK) NF membrane was prepared by interfacial polymerization method while positively charged quaternized poly (phthalazinone ether sulfone ketone) (QAPPESK) membrane was prepared by phase inversion method. QAPPESK performed higher dye rejection and flux compared with the PIP/PPESK NF membrane. Furthermore, QAPPESK showed excellent thermal and fouling resistance.

A direct treatment of a textile industry effluent by means of a combination of ultrafiltration (UF) followed by a final NF stage was studied by Alcaina-Miranda et al. (2009). The UF results showed that the highest permeate fluxes were achieved at pH 11. Related to NF experiments, no influence of pH was found for the permeate flux; however, the pH effect was evident for salt rejection.

Three different NF membranes were tested to treat the biologically treated wastewater in a laboratory plant. For all membranes, the COD values in the permeate were negligible and flux rejection was not severe even for the maximum operating volume concentration factor (VCF) (Bes-Piá, et al., 2009).

The wastewaters resulting from different baths of a dyeing factory specialized in denim fabric were collected and treated by an activated sludge plant coupled with either NF or RO to recycle water and reuse in the process. The NF experiments showed that 11 bar was a suitable operating pressure. It allowed a yield of 9% and a COD reduction and Total Dissolved Solids (TDS) rejection of 62%, values in conformity with the local limits for water reuse. Results from low pressure RO experiments showed

that the yield obtained at the same pressure of 11 bar was much lower than that obtained with NF (4% versus 9%), although there was a 30% increase in rejection performance (Amar et al., 2009).

According to Lau and Ismail (2009), it is difficult to draw a general conclusion on the feasibility and the efficiency of NF for dyeing effluent treatment in the textile industry due to the large variability of the textile wastewater parameters and the quality of permeate required. However, based on the numerous studies conducted so far, NF membranes have proved applicable in dealing with textile wastewater which is highly colored as well as highly loaded with monovalent and/or divalent salts.

The UF was studied by Simonič (2009) as a wastewater pre-treatment technique for the decolorization of residual dye-bath effluents after dyeing cotton/polyamide blends using reactive and acid dyes. The results obtained showed that UF was an appropriate method for COD removal and decolourization of combined reactive and acid dye-baths. Three membrane processes (microfiltration-MF, UF and NF) were used by Fersi et al. (2009) for the treatment of textile effluent samples. The various filtration resistances were calculated in order to determine the principal mechanism for UF and NF processes. Cake formation constant were investigated by using linearized forms of cake filtration equations obtained by Wiesner and Aptel. Srisukphun et al. (2009) investigated the relationship between foulant interactions and fouling of reverse osmosis membrane during textile wastewater reclamation. The results showed that the surfactant yielded higher flux decline than reactive dye and effluent organic matter (EfOMs). A mathematical model was derived from the assumption that the deposited monomer was the main cause of flux decline. According to this model, mixed surfactant as commercial soaping agent presented the highest fouling coefficient.

Adsorption. In their review, Gupta and Suhas drew (2009) provided an overview of the low-cost alternative adsorbents (LCAs), comprising natural, industrial as well as synthetic materials/wastes and their applications for dyes removal. In addition, they included also various other methods used for the same purpose.

Hassan et al. (2009) investigated the use of Sorel's cement for removal of reactive dyes (RY-145, RR-194 and RB-B) in textile wastewater. The adsorbed amount of reactive dyes increased with the increase of the contact time and adsorbent dosage reaching a maximum equilibrium for 10^{-4} M of the dye at 30 min and 0.02 g adsorbent. The adsorbed amounts decreased with increasing of temperature. The adsorption process followed Langmuir isotherm.

Activated carbon developed from agricultural waste material was characterized and utilized by Khaled et al. (2009a) for the removal of Direct Navy Blue 106 (DNB-106) from wastewater. Adsorption studies were carried out at different initial concentrations of DNB-106, contact time, pH and sorbent doses. The maximum adsorption capacity was 107.53 mg/g for 150 mg/L of DNB-106 concentration and 2 g/L carbon concentration. Chaari et al. (2009) studied the adsorption of Indanthrene Blue RS (Color Index, C.I., Vat Blue 4) on smectite-rich clayey rock

(AYD) and its sulphuric acid-activated products (AYDS) in a batch system with respect to contact time, pH and temperature. The adsorbents employed were characterized by X-ray diffraction, infrared spectroscopy and specific surface area, cation exchange capacity and point of zero charge. The retention capacities were shown to be 13.92 and 17.85 mg/g for untreated clay (AYD) and AYDS, respectively, according to the Langmuir model.

According to Dulman and Cucu-Man (2009), the beech wood sawdust can be considered an efficient non-conventional adsorbent for removal of the three commercial dyes: Direct Brown (DB), Direct Brown 2 (DB2) and Basic Blue 86 (BB86). The extent of dye removal decreased with increasing of the solution pH for DB and DB2. The preference for dyes increased as follows: DB>DB 2>BB 86. The maximum retention capacity was 526.3 mg/g for DB (with a content of ~60% pure dye).

Extracted babassu coconut (*Orbignya speciosa*) mesocarp (BCM) was successfully applied by Vieira et al. (2009) as a biosorbent for aqueous Blue Remazol R160 (BR160), Rubi S2G (R S2G), Red Remazol 5R (RR5), Violet Remazol 5R (VR5) and Indanthrene Olive Green (IOG) dye solution treatment. The natural sorbent was processed batch-wise while varying several system parameters such as stirring time, pH and temperature. The maximum adsorption was obtained at pH 1.0 for all dyes. Ozdemir et al. (2009) conducted fixed-bed column studies to find out the effectiveness of surfactant-modified zeolite (SMZ) bed for color removal from real textile wastewater. Optimum modification conditions were found as lower values of surfactant concentration (1 g/L) and flow rate (0.015 L/min) for higher color removal. Design parameters for the SMZ column, like time required for adsorption zone to move, height of exchange zone, and rate at which the adsorption zone moves, were calculated as 616 min, 13.91 cm and 22.5×10^{-3} cm/min, respectively. Ahmad and Hameed (2009) used chemical activation to convert bamboo into activated carbon with relatively large Brunauer-Emmett-Teller (BER) surface area. Under conditions of pH=3, sorbent dose=0.30 g/100 mL solution and time=10h, color and COD reduction were found to be 91.84% and 75.21%, respectively. According to Khaled et al. (2009b), kinetic and equilibrium studies demonstrated that activated carbon developed from orange peel can be effectively used as an adsorbent for the removal of Direct Yellow 12 (DY 12) from aqueous solution. The results showed that acidic pH (1.5) supported the adsorption of DY12 on the activated carbon. The maximum removal was 96% for 125 mg/L DY12 concentration on 5 g/L carbon concentration.

The sludge collected from the biological coke wastewater treatment plant, was used by Junxiong et al. (2009) as a low-cost adsorbent for the removal of Methylene Blue (MB) and Reactive Red 4 (RR4) from aqueous solution. The maximum removal of RR4 by protonated sludge was 73.7 mg/g at pH 1; the maximum removal of MB by sludge was 235.3 mg/g at pH 9. The anionic functional groups, phosphonate and carboxyl group, were identified as the binding sites for the cationic MB; the amine groups were indentified to bind RR4. Leechart et al. (2009) studied utilization of wood-shaving bottom ash (WBA), WBA/H_2O (made by treating WBA

with water) and WBA/H_2SO_4 (made by treating WBA with 0.1 M H_2SO_4) for the removal of Red Reactive 141 (RR141). The studies indicated that the decolorisation mechanism involved both chemical adsorption and precipitation with calcium ions. In addition, WBA/H_2SO_4 surface might contain sulphate-cation complexes that were specific to enhancing dye adsorption. The maximum adsorption capacities of WBA/H_2O, WBA/H_2SO_4 and activated carbon obtained from a Langmuir model at 30°C were 24.3, 29.9 and 41.5 mg/L, respectively.

Çelekli et al. (2009) reported that the filamentous green alga, *Spirogyra majuscule*, showed to have the potential to remove Reactive Red 120 (RR120) from aqueous solution at different pH regimes. Freundlich and Redlich-Peterson models well fitted to the experimental data. The thermophilic cyanobacterium *Phormidium* sp. was used and evaluated by Aksu et al. (2009) as a possible biosorbent for the single chromium(VI) and binary chromium(VI) and Remazol Black B (RRB) dye treatment. The results obtained showed that although the microalgae has a reasonable uptake capacity for chromium(VI), it exhibited a considerable potential for the removal of RRB reactive dye.

Akar et al. (2009) assessed the effects of process variables such as initial pH, biosorbent dosage, contact time, temperature and ionic strength, on the adsorption of reactive textile dye RR198 by olive pomace. The highest adsorption capacity was found at pH 2 and the needed time to reach the biosorption equilibrium was 40 min with a biosorbent concentration of 3.0 g/L. The waste biomass of olive oil industry displayed biosorption capacities ranging from 6.05×10^{-5} to 1.08×10^{-4} mol/g at different temperatures.

Chan et al. (2009) produced the activated carbon using phosphoric acid treatment of the waste bamboo scaffolding and activated at either 400 or 600°C. The BET surface area increased with increasing the acid to bamboo ratio (Xp). In a single component system it was found that dye with smaller molecule size, Acid Blue 25 (AB25), was readily adsorbed onto the carbon, while the larger size dye, Acid yellow 117 (AY117), showed little adsorption.

Activated (AC-PW) and non activated (C-PW) carbonaceous materials were prepared by Calvete et al. (2009) from the Brazilian pine-fruit shell (*Araucaria angustifolia*) and tested as adsorbents for the removal of Procion Red MX 3B dye (PR-38) from aqueous effluents. PR-3B uptake was favorable at pHs ranging from 2.0 to 3.0 for C-PW and from 2.0 to 7.0 for AC-PW. The contact time to attain equilibrium using C-PW and AC-PW as adsorbents was 6 and 4h at 298K, respectively. Uğurlu (2009) investigated adsorption of Remazol Red B (RRB) on the thermal activated sepiolite (TAS) and acid activated sepiolite (AAS) from aqueous solutions at different temperature, contact time and solution pH values. According to the results, the equilibrium time and optimum pH value were found to be 120 min and ~2-3, respectively. Besides, AAS samples displayed higher adsorption capacity that TAS.

The following bio/natural waste materials were selected by Kaushik et al. (2009) as adsorbents for reducing the organic chemical load in direct dyes effluents: Sugarcane bagasse pith (SB), Saw dust (SD)-the plant

origin products- and Brick powder (BP) –a silica based material obtained from earth's crust on thermal heating. An appreciable decrease in COD values was observed in the samples treated with the selected adsorbents; better performance were achieved with Sugarcane bagasse pith. Al-Ghouti et al. (2009) demonstrated effectiveness of manganese oxides-modified diatomite (MOMD) to remove basic and reactive dyes from aqueous solution. The adsorption capacity of MOMD for Methylene Blue (MB), hydrolysed Reactive Black (RB) and hydrolysed Reactive Yellow (RY) was 320, 419 and 204 mg/g, respectively.

According to Vijayaraghavan et al. (2009), a complex Remazol dye effluent, comprised of four reactive dyes (Reactive Black5, RB5, Reactive Orange 16, RO16, Remazol Brilliant Blue R, RBBR, and Remazol Brilliant Violet5R, RBV) and auxiliary chemicals, was decolorized using SPS-200 (sawdust-based) and SPC-100 (coal-based) activated carbons. SPS-200 showed high adsorption capacities towards all four the reactive dyes (RB5, RO16, RBBR and RBV), along with fast adsorption kinetics for single component systems.

A low-cost waste biomass derived from canned food plant, was tested by Akar et al. (2009) for its ability to remove reactive textile dye from aqueous solutions. Optimum decolorization was observed at pH 2.0 and 1.6 g/dm^3 of biomass dosage within 20 min. The thermodynamic parameters for the biosorption process were also calculated. The leaf sheath fibres of the Mediterranean sea grass *Posidonia oceanic* (L.) were used by Ncibi et al. (2009) as low cost, available and renewable biological adsorbent for the removal of a metal complex textile dye (Alpacide Yellow) from aqueous solutions. Maximum color removal was observed at pH 2. Biosorption capacity was enhanced by increasing biomass quantity up to 10 g/L for an initial dye concentration of 50 mg/L.

Biological Processes

Enzymes. Degradation of a mixture of three reactive textile dyes (Reactive Black 5, Reactive Yellow 15 and Reactive Red 239), simulating a real textile effluent, by commercial laccase, was investigated in a batch reactor. A significantly high discoloration was achieved as measured by either the percentage of absorbance reduction at the maximum absorbance wavelength or by the total color removal in all the visible spectrum. The proposed kinetic model showed to be applicable in predicting the behavior of mixed reactive dyes degradation by commercial laccase (Cristóvão et al., 2009). Non-porous poly(glycidyl methacrylate/ethyleneglycol dimetacrylate) (poly(GMA/EGDMA)) beads were prepared by suspension polymerization. The enzyme (laccase) was covalently immobilized onto plain and spacer-arm attached poly(GMA/EGDMA) beads. The amount of immobilized enzyme on the plain and space-arm attached beads was determined as 5.6 and 4.9 mg/g, respectively. The immobilized laccase was operated in a batch system and textile dye Reactive Red 120 was successfully decolorized in the enzyme reactor (Arica et al., 200). A laccase requiring optimum temperature 60°C, pH 4.0 for the activity and having apparent molecular weight 43 000 Da was purified by Kalme et al. (2009) from *Pseudomonas*

desmolyticum NCIM 2112 by three steps, including heating, anion exchange, and molecular sieve chromatography. UV-vis analysis showed the decolorization of Direct Blue 6, Green HE4B and Red HE7B in the presence of laccase.

Biocatalytic treatment of a synthetic dye house effluent, simulating a textile wastewater containing various reactive dyestuffs (Reactive Yellow 15, Reactive Red 239 and Reactive Black 5) and auxiliary chemicals, was investigated by Cristóvão et al. (2009) in a batch reactor using a commercial laccase. A high decolourisation efficiency was obtained at the maximum wavelength of Reactive Black 5. The decolorisation at the other dyes wavelengths and the total decolorisation based on all the visible spectrum were not so good. The influence of different metal ions on laccase activity and laccase-catalyzed dye decolorization was investigated by Murugesan et al. (2009) under in vitro conditions using crude laccase obtained from a white rot fungus *Ganoderma lucidum*. Laccase activity was enhanced by metal ions such as Ca^{2+}, Co^{2+}, Cu^{2+} and Zn^{2+} at low concentrations (1 mM). Increasing the concentration of metal ions except that of Cu^{2+} and Zn^{2+}, up to 5 mM and above decreased the enzyme activity. Among several heavy metals, Fe^{2+} highly inhibited the enzyme activity.

Sedighi et al. (2009) investigated the effect of Tween80, Mn(II) and veratryl alcohol on the production of ligninolytic enzymes of *Phanerochaete crhysosporium* in a packed-bed bioreactor using small pieces of Kissiris as carrier. The enzyme activities determined decolorization and COD reduction of the textile effluent containing azo dye (Astrazon Red FBL). The maximum decolorization (87%) and COD removal (42%) were both achieved when only Tween80 (0.05% w/v) was added to the effluent. Bitter gourd peroxidase immobilized on the surface of concanavalin A layered calcium-alginate-starch beads was successfully used by Matto and Husain (2009a) for decolorization of textile industrial effluent. The presence of some redox mediators was needed to achieve color removal. Immobilized bitter gourd peroxidase decolorized more than 90% effluent after 3h of incubation in a batch process. The system was capable of decolorizing 40% effluent even after 2 moths of continuous operation. Matto and Husain (2009b) also employed an inexpensive immobilized turnip peroxidase for the decolorization of some direct dyes in batch and continuous reactors. Wood shaving was investigated as inexpensive material for the preparation of bioaffinity support. Concanavalin A-wood shaving bound turnip peroxidase exhibited 67% of the original enzyme activity. Aravelo Niño et al. (2009) investigated the ability of wild type ligninolytic fungi to produce laccase immobilizated in pectin-chitosan beads. Liu et al. (2009) demonstrated the dye-decolorizing potential of bilirubin oxidase (BOX) for an athraquinome dye, Remazol Brilliant Blue R (RBBR). The dye was decolorized 40% within 4h by the BOX alone, whereas it was more efficient in the presence of 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), showing 91.5% decolorization within 25 min. Dye removal efficiency decreased whit increasing RBBR concentration, and a marked inhibition effect was exhibited when the dye concentrations were above 100 mg/L.

Yeasts. According to Saratale et al. (2009) Navy blue HER was decolorized and degraded within 24h by *Trichosporon beigelii* NCIM-3326 under static conditions. Among five strains, *T. beigelii* gave better performance on the decolorization of Navy blue HER along with a 95% TOC reduction within 24h. Bioaccumulation of chromium(VI), nickel(II), copper(II) and reactive dye by yeast *Rhodotorula mucilaginosa* was investigated by Ertuğrul et al. (2009) in media containing molasses as a carbon and energy source. Optimal pH values for the yeast cells to remove pollutants were pH 4 for copper(II) and dye, pH 6 for chromium(VI) and dye, and pH 5 for nickel(II) and dye in media containing 50 mg/L heavy metal and 50 mg/L Remazol Blue. The maximum dye bioaccumulation was observed within 4-6 d and uptake yields varied from 93% to 97%.

Bacterial Processes. According to Saratele et al. (2009) a developed consortium-GR, consisting of *Proteous vulgaris* NCIM-2027 (PV) and *Micrococcus glatamicus* NCIM-2168 (MG), completely decolorized an azo dye Scarlet R under static condition with an average decolorization rate of 16.666 μg/h, which was much faster than that of the pure culture. Consortium-GR gave best decolorization performance with nearly complete mineralization of Scarlet R (over 905 Total Organic Carbon, TOC, and COD reduction) within 3h, which was much shorter than the individual strains. *Brevibacillus laterosporus* MTCC 2298 showed 87% decolorization of Golden Yellow HER within 48 h under static conditions at the concentration of 50 mg/L; however, no significant change in the decolorization performance was observed under shaking conditions. Decolorization performance was maximum (74%) at the pH 7.0 and 30°C (Gomare et al., 2009). *Acinetobacter calcoaceticus* was employed by Ghodake et al. (2009) for the degradation of Direct Brown MR (DBMR), in order to analyze mechanism of the degradation and role of inhibitors, redox mediators and stabilizers of lignin peroxidase during decolorization.

A mixture of 200 mg/L Reactive Black 5 and 200 mg/L Reactive Red 2 was treated in batch experiments using microorganisms growing on forest residue wood chips in combination with or without added white rot-fungus, *Bjerkandera* sp. BOL 13. The results showed that the microorganisms were capable of decolourizing the mixture of two dyes, adding extra nutrients approximately doubled the decolourization rate (Forss and Welander, 2009). Silveira et al. (2009) tested four *Pseudomonas* species against 14 commercial industrial dyes. *Pseudomonas cepacia* exhibited no growth at all on plates containing dyes (1 g/L), whereas *Pseudomonas aeruginosa, Pseudomonas oleovorans* and *Pseudomonas putida* exhibited considerable growth. Decolourization in a liquid culture revealed that *P. oleovorans* was more viable for decolourizing textile dyes, as it achieved over 80% colour removal for two of the14 studied. Mansour et al. (2009) found *Pseudomonas putida* mt-2 able to decolorize and detoxify completely Acid Violet 7 (AV7) at a concentration up to 200 mg/L. The expression of an azoreduction system by the bacterium was validated by identification in static biodegradation medium of the amines deriving from azoreduction, while, in shaken incubation (best

oxygenation) these amines were not detected as they were further metabolized.

According to Sharma et al. (2009a) application of the bacterial strain *Bacillus subtilis* for decolorization of textile azo dye Disperse Yellow 211 showed to be a practical approach. They found that Response Surface Methodology (RSM) is a suitable tool to optimize the best culture conditions for achieving maximum decolorization of the dye. By applying Box-Behnken design to the optimization experiments, it was possible to investigate the process variables completely and achieve decolorization values up to 80%. A bacterial strain, CK3, with remarkable ability to decolorize the reactive textile dye Reactive Red 180 (RR180), was isolated by Wang et al. (2009) from the activated sludge collected from a textile mill. Phenotypic characterization and phylogenetic analysis of the 16S rDNA sequence indicated that the bacterial strain belonged to the genus *Citrobacter*. It showed decolorizing ability against both azo and anthraquinone dyes. Anaerobic conditions with 4 g/L glucose, pH 7.0 and 32°C, were considered to be the optimum decolorizing conditions. Wang et al. (2009) carried out studies on the decolorization of Reactive Black 5 (RB5) by a newly isolated bacterium, EC3, belonging to the genus *Enterobacter*. The optimal decolorizing activity was found under anaerobic conditions with glucose supplementation, at pH 7.0 and 37°C.

According to Franciscon et al. (2009), four different azo dyes were decolourized and biodegraded in a sequential microaerophilic-aerobic treatment by a facultative *Klebsiella* sp. Strain VN-31, a bacterium isolated from activated sludge process of the textile industry. TOC reduction for the growth medium plus dyes was about 50% in the microaerophilic stage and about 80% in the aerobic stage.

Franciscon et al. (2009) reported about successful decolourization of four different azo dyes under microaerophilic conditions by a facultative *Staphylococcus arlettae*, isolated from an activated sludge process in a textile industry. The presence of aromatic amine in the microaerophilic stage and its absence in the following aerobic stage, indicated the presence of azoreductase activity and an oxidative biodegradation process, respectively.

Two aerobic bacterial consortia were developed by Tony et al. (2009) from a textile wastewater treatment plant. Among the two, SKB-II was the most efficient in decolorizing individual as well as mixture of dyes. Liang et al. (2009) reported that significant improvements were observed in the removal rates of Dissolved Organic Carbon (DOC), COD and Oxygen Uptake Rate (OUR) with 121%, 156% and 121% of those of the control, respectively, when 0.5-2.0 mg/L thiamine was added to the wastewater treatment system. Physicochemical and bacteriological status of a local textile mill effluent showed considerably high values of temperature (40°C), pH (9.50), Electrical conductivity (EC) (3.57 μS/m), BOD (548 mg/L), COD (1632 mg/L), TSS (5496 mg/L), Total Dissolved Solids, TDS (2512 mg/L), heavy metals ions (0.28-6.36 mg/L) and color above the prescribed fresh water limits. However, according to Ali et al. (2009), a considerable decline in almost all pollution indicators from source to sink indicated signs of natural remediation.

Khelifi et al. (2009) investigated the aerobic biodegradability of the indigo dye-containing textile wastewater using a Continuously Stirred Tank Reactor (CSTR). The molecular fingerprint established using polymerase chain reaction-single stranded conformation polymorphism (PCR-SSCP) methods showed that bacterial community profiles changed simultaneously with the increase of the wastewater loading rates (WLR). For the two WLR of 0.28 g/L•d and 0.37 g/L•d, the reactor maintained good performances, suggesting that the large bacterial community presented a high specific activity. The effects of the increasing WLR was also studied by Khelifi et al. (2009) using an up-flow anaerobic fixed bed bioreactor. The analysis showed that WLRs variations influenced the bacterial community structure and affected the reactor performance. For WLRs of 0.34-0.85 g/L•d, the bioreactor showed a high performance and maintained highest colour and COD removal with average values of 95% and 90%, respectively. The gas production rate increased when WLR increased.

Yigit et al. (2009) evaluated performance of a pilot-scale membrane bioreactor (MBR) system for the treatment of a highly concentrated mixed wastewater from wet processes (dyeing, finishing and sizing) of a denim producing textile industry. During the 3-months period of operation, despite the high dissolved solids content in the influent, very high treatment efficiencies were achieved. The average values of some effluent quality parameters found in the entire operation period were: color, 53 Pt Co; turbidity, 0.31 NTU; Total Suspended Solids, TSS, 06 mg/L; BOD_5, 15 mg/L; COD, 37 mg/L; NH_3-N, 1.0 mg/L; NO_3^--N, 9.6 mg/L and Total Nitrogen (TN), 10.5 mg/L.

Contrary to virtually complete decoloration of an azo dye (Acid Orange II, 100 mg/L) in pure culture batch tests, a fungal membrane bioreactor (MBR) achieved 93% removal during long-term non-sterile operation at a hydraulic retention time (HRR) of 1d. Bacterial contamination on fungal activity had detrimental effect and suggested close relationship among fungal morphology, enzymatic activity and decoloration activity (Hai et al., 2009). You and Teng (2009a) reported partial treatment of the azo dye Reactive Black 5 (RB5) in an anaerobic Sequencing Batch Reactor (SBR); then, it was further treated either in an aerobic membrane bioreactor (AOMBR) or in combined aerobic membrane bioreactor/reverse osmosis (AOMBR/RO) process. The results showed that RB5 was degraded to form aromatic amine intermediate metabolites, which were further mineralized in the AOMBR. Although all effluents from the AOMBR and the AOMBR/RO processes met the law standards, irrespective which membrane was used in the aerobic stage, the effluent from the AOMBR/RO process met the criteria for reuse for toilet flushing, landscaping, irrigation and cooling water purposes. You and Teng (2009b) also studied degradation of RB5 using anaerobic SBR combined with an aerobic membrane bioreactor (aerobic MBR). In addition the anaerobic RB5 degrading bacteria were isolated and their individual performance tested separately. Nearly 92.3% and 5.2 %of COD removal and 74.6% and 9.1% of true color removal was achieved

using the anaerobic SBR and the aerobic MBR, respectively.

Chang et al. (2009) evaluated the effectiveness of zeolite media in the Biological Aerated Filter (BAF) reactor for the treatment of textile wastewater. Performances of zeolite resulted better than those obtained from sand and granular activated carbon (GAC) as packing media. The different mechanisms of ion exchange, nitrification and cell synthesis concomitantly occurred on zeolite media for the removal of ammonium. A fluidized bed reactor (FBR) with activated carbon as support material was used by Haroun and Idris (2009) to investigate removal efficiency of COD, BOD and color of textile wastewater. Results indicated that the anaerobic treatment was possible with the supplementation of substrate additives as external carbon source such as glucose (about 0.6 g/L). The study showed 98% soluble COD, 95% BOD_5, and 65% color reduction. A modified version of the International Water Association-Activated Sludge Model 1 was proposed by Lubello et al. (2009) capable of correctly simulating the production of solids over a wide range of solids retention time (SRT). In combination with results of the respirometric tests, the proposed model was applied to two pilot scale Membrane Biological Reactors (MBRs) that treated textile and tannery wastewater. Kagalkar et al. (2009) found tissue cultured plants of *Blumea malcolmii* to decolorize Malachite green, Red HE8B, Methyl Orange, Reactive Red 2 and Direct Red 5B at 20 mg/L concentration to varying extent within three days. A significant induction in the activities of the enzymes DCIP reductase, azoreductase and riboflavin reductase indicated their probable role in the phytotransformation of the Direct Red 5B. Since *B. Malcolmii* plants decolorized majority of dyes studied, the authors concluded that can be explored for the phytoremediation of dye contaminated sites.

According to Davies et al. (2009), phytoremediation of Acid Orange 7 (AO7) in a pilot constructed wetland (CW) was feasible even for very high concentrations (AO7=748±42 mg/L). Removal efficiencies of approximately 68±8%, 69±8% and 67±4% were obtained for AO7, COD and TOC, respectively. A study of the gene-expression for the most widely used plant in CWs (*Phragmites australis*) while integrated in the AO7 wastewater treatment was developed. The results obtained indicated that AO7 was a chemical stressor agent when in contact with *P. australis* root system, as foliar gene expression of reactive oxygen species (ROS)-scavenging enzymes that belong to plant antioxidative defence system was activated. Treatment of azo dye AO7 was studied also by Ong et al. (2009) using an up-flow CW (UFCW) at laboratory-scale, with and without supplementary aeration. The results showed that supplementary aeration in UFCW reactor could control the ratio of anaerobic and aerobic zones effectively. The anaerobic zones at the lower bed facilitated the decolorization whereas the aerobic zones at upper bed determined the biodegradation of organic pollutants and also mineralization of aromatic amines generated from the reduction of the azo dye. Ong et al. (2009) also studied the treatment of AO7 and nutrients using five laboratory-scale UPCW with and without supplementary aeration and with different emergent plants. The AO7 removal efficiency was above 95% in all UPCW

reactors and most of the color was extensively removed in the anaerobic region of the UFCW beds. The removal of Total Nitrogen (TN) and Total Phosphorous (TP) were in the range of 60-67% and 26-37%, respectively, among the UFCW reactors.

A simple mechanistic model of a pulse-fed vertical flow CW was presented by Freire et al. (2009). The model showed to accurately reproduce measurements of outlet flow and outlet concentration obtained while treating a synthetic wastewater containing the azo dye AO7. The treatment efficiency determined while operating at pseudo-stationary state for a high AO7 inlet concentration of 692±92 mg/L were 68±5% and 70±21% in summer and winter, respectively, for a flooding level of 21% and a pulse feeding of 13 min each 3h.

Fungal Processes. Couto (2009) reviewed the application of fungal immobilization to dye removal. The author concluded that, although a variety of carrier materials have been tried for fungal immobilization, there are very few reports containing these in terms of their performance, long-term stability and cost. Also, an important area of research requiring greater focus is the bioreactor design and its long-term operation. In their review, Kaushik and Malik (2009) focused on the decolourization of dye wastewaters through fungi via two processes (biosorption and bioaccumulation) and discussed the effect of various process parameters like pH, temperature, dye concentration etc., on dye removal efficiency of different fungi. Various enzymes involved in the degradation of the dyes and the metabolites thus formed were compiled. The study indicated that fungal decolourization have a great potential to be developed further as a decentralized wastewater treatment technology for small textile or dyeing units.

Sharma et al. (2009b) studied decolorization of diazo dye Acid Red 151 (AR151) from simulated dye solution using a fungal isolate *Aspergillus fumigates fresenius*. The central composite matrix and response surface methodology (RSM) were applied to design the experiments to evaluate the interactive effects of temperature, pH and initial dye concentration. The RSM indicated that optimal conditions for maximum decolorization were: 150 mg/L dye concentration, pH 5.5 and temperature of 30°C. A systematic optimization study of the important variables influencing the decolorization of Reactive Orange 16 (RO16) and Reactive Red 35 (RR35) dyes by white rot-fungus *Trametes versicolor* was carried out by Srinivasan and Murthy (2009). The effect of concentration of dye, glucose and ammonium chloride on decolorization was studied and optimized using RSM. Isolation of a novel bacterial strain was performed by Kalyani et al. (2009) from the waste disposal sites of local textile industries. Detailed taxonomic studies identified the organisms as *Pseudomonas* species and designated as strain *Pseudomonas* sp. SUK1. The isolate was able to decolorize sulfonated azo dye (Reactive Red 2) in a wide range (up to 5 g/L), at temperature of 30°C and pH range of 6.2-7.5 in static conditions.

The bioremediation of textile direct violet dye by *Aspegillus niger* fungal strain was studied by El-Rahim et al. (2009) under different pH values in the range 2-11. The dye reached maximum bioremoval with 92.4%, 64.0% and

62.3% at pH values of 2, 3 and 9, respectively, at 24h incubation. At the end of the experiments, the treatment by fungal strain could reduce COD value of synthetic dye solution by 76-91%. Asgher et al. (2009) achieved variable decolorization efficiency for industrial effluents of different colors using white rot fungus *Coriolus versicolor*. Decolorization potential of the fungus was enhanced through the addition of starch as carbon source.

A continuous biofilm decolorizing system with high efficiencies of dye degradation and textile wastewater treatment was established using selected fungal consortium. The colony forming units (CFUs) ratio of fungi to bacteria stabilized between 51.8:1 and 6.8:1 under the influent conditions of various simulated and real textile wastewater. The results indicated that the dominant population preserved in the system was yeasts belonging to the genus *Candida* (Lu et al., 2009). Verma (2009) used two-marine derived ascomycetes and two basidiomycetes fungi for treatment of raw dye-containing effluents, varying in the pHs and compositions. Textile effluent (TEA) with pH 8.9 containing azo dye and textile effluent (TEB) with pH 2.5 containing reactive dye were decolorized by 70-90% by these fungi. Effluents at 20, 50 and 90% concentration were added to the culture medium. A reduction of 80-90% in COD and total phenolics was brought about by these fungi.

Combined

Photodegradation of real textile effluents by advanced oxidation process (AOP) using TiO_2/H_2O/sunlight system was studied by Garcia et al. (2009). Solar radiation demonstrated to be as efficient as or even more efficient than artificial radiation and also allowed a reduction in effluent treatment operational costs. According to Berberidou et al. (2009), the combined system made by photocatalytic oxidation with membrane filtration was capable to achieve complete decolorization as well as more than 95% reduction of the initial organic content and salinity of a synthetic dyestuff effluent (SDE) containing the Reactive Black 5 (RB5). Chang et al. (2009) proposed a hybrid system consisting of ozone, UF and RO for the treatment of Digital Textile Printing (DTP) wastewater. Prior to UF and RO, ozone was introduced to the DTP wastewater to reduce the organic loading to membrane filtration as well as to treat the concentrates recycled from UF and RO. Water quality of the final effluent (ozone+UF+RO) of the DTP wastewater was good enough for direct discharge or reuse.

Coagulation, MF and UF processes were applied as pre-treatment alternatives prior to NF application to an indigo dyeing wastewater representative of the dyeing process of a denim textile mill. The results revealed that coagulation was not an effective pre-treatment method due to the high dose of coagulant required. Sequential application of MF and UF and only MF were superior to the coagulation process in terms of color and COD reductions. NF experiments conducted using pre-treated wastewater via only MF provided 99% color and 97% COD removals, thus representing the optimum treatment scheme for the reuse of the dyeing wastewater (Unlu et al., 2009).

An integrated wastewater reclamation system was tested by Lu et al. (2009) at pilot-scale (300 m^3/d) for

printing and dyeing wastewater treatment from a textile factory. The wastewater was firstly hydrolyzed under anoxic conditions and then was treated under aerobic conditions. The biologically treated effluent was finally filtered by sub-filter technology. The treated effluent quality satisfied the requirement of water quality for printing and dyeing process.

Aouni et al. (2009) showed that electrocoagulation followed NF process was suitable for producing a reusable water quality for a textile effluent sample. The electrochemical treatment was intended primarily to remove color and COD while NF was used to further improve the removal efficiency of color, COD, conductivity, alkalinity and TDS. Lee et al. (2009) investigated the addition of ferric and polyaluminum coagulants with regard to controlling membrane fouling during the UF of textile wastewater generated from the water jet loom process. The dosing of coagulants to textile wastewater exhibited the best control of fouling for the UF membrane, with a molecular weight cut-off (MWCO) of 10 kDa, among the MF and UF membranes tested. Flux decline was mitigated when the dosage of ferric chloride coagulant increased up to 0.5 mM as Fe, whereas polyaluminum chloride (PAC) exacerbated fouling at a larger dosage. Various combinations of physicochemical and membrane processes were studied by Harrelkas et al. (2009) for the treatment of textile wastewater. The best results were obtained in terms of COD removal (> 80%) for the coagulation/flocculation (CF)/powdered activated carbon (PAC) combination and of color removal (74%) for coupling coagulation/UF. However, the quality of the water treated by CF/PAC or coagulation/UF was still not good enough to be reused in the industry.

According to Paździor et al. (2009), the anaerobic biological azo dyes reduction process was successfully applied to decolourization of the concentrates from the NF treatment of real textile effluents. The anaerobic phase was followed by aerobic oxidation aimed at the destruction of aromatic amines released from azo dye. El-Gohary and Tawfik (2009) investigated reduction of color and COD by means of coagulation/flocculation (CF) followed by SBR process. The experimental results showed that treatment with alum aided with cationic polymer followed by SBR was very effective, achieving overall efficiencies of 86.9% COD, 92.6% BOD_5, 93.8% TSS and 92.2% oil and grease.

A combination of Fenton's reagent oxidation with biological degradation in a SBR was successfully applied to the removal of organic compounds and colour from a synthetic effluent simulating a cotton dyeing wastewater. A central composite design (CCD) was firstly used to determined the values of the operating conditions of the chemical oxidation stage which maximized the dissolved organic carbon (DOC) and color removal and increase the effluent's biodegradability (Rodrigues et al., 2009).

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