CHAPTER 2

LITERATURE SURVEY

2.1 TREATMENT OF PULP AND PAPER INDUSTRY EFFLUENT

Lee et al (1978) used algae to decolourize diluted bleach kraft mill effluents. Based on the experimental result, they found that pure and mixed algal cultures removed 70% of colour within 2 months of incubation. All algae exhibited a similar colour reduction pattern consisting of a phase with rapid and accelerating removal rate and a phase with declining rate. Colour removal was most effective during the first 15 to 20 days of incubation, and then gradually dropped. Colour removal by algae is caused by metabolic transformation of coloured molecules to non coloured molecules with limited degradation of molecular entities.

Prasad and Joyce (1991) used Trichoderma sp., to decolourize the kraft bleach plant effluent. Glucose was found to be the most effective carbohydrate utilized by the fungus as it stimulated substantial colour reduction without any increase in COD. Addition of nitrogen did not stimulate the decolourization process indicating that it is not a rate-limiting factor. The optimum pH for decolourization and growth was 4. Under optimal conditions, total colour and COD decreased by almost 85% and 25% respectively, after cultivation for 3 days.
Royer et al (1991) studied the use of the pellets of *C. versicolor* to decolourize ultra filtered kraft liquor in non sterile condition with a negligible loss of activity. The rate of decolourization was linearly varied with respect to the liquor concentration and an effective decolourization of effluent having 400-500 Unit^{-1} was obtained in presence of a simple carbon source such as glucose. In the repeated batch culture, the pellets exhibited a loss of activity dependent on the initial colour concentration. *C. versicolor* produces an extra cellular laccase which plays a role in lignin biodegradation.

Roy-Arcand and Archibald (1991) studied the treatment of bleach plant effluent using ozone and the fungus *C. versicolor*. Both ozone treatment and biological treatment effectively destroyed effluent chromophores, but the fungal process resulted in greater degradation as expressed by COD removal. Monoaromatic chlorophenolics and toxicity were removed partially by ozone and completely by *C. versicolor*. Molecular weight distributions showed roughly equal degradation of all sizes of molecules in both treatment methods. The combination of an ozone treatment with a subsequent fungal treatment revealed a synergism between the two decolourization mechanisms on Kraft Bleachery Effluent. Effluent was pretreated with ozone (110-160 mg l^{-1}) or *C. versicolor* (24 h with 2-5 g l^{-1}, wet weight fungal biomass). The pretreatment was followed by 5 d incubation with *C. versicolor*. It was noted that partial colour removal by ozone pretreatment allowed more effective colour removal by the fungus than that by fungal pretreatment. After 20 h, 46-53% decolourization was observed for ozone pretreated effluents, compared to 29% for fungal treatment alone. The contribution of ozone seemed to be most important in the first 24 h following the pretreatment. After that decolourization rates and extents did not change as much. Ozone pretreatment also produced a small improvement in the bioavailability of effluent organics to the fungus.
Pratima Bajpai et al (1993) used pellets form of *T. versicolor* strain B-7 for decolourization of kraft bleach plant effluent. The fungus was used in the form of pellets, allowing its use in large amounts and eliminating the problem of recycling the biomass. The mycelial pellets oxidized the chromophores of the effluent in presence of any of the co-substrates sucrose, glucose, starch, ethanol, carboxymethyl cellulose, micro crystalline cellulose, pulp and malt extract. The highest decolourization was obtained for glucose. Optimum pH and temperature were 4.5-5.5 and 30°C, respectively. In the batch reactor with an effluent of 7000 colour units per liter, the maximum colour reduction of 93% was obtained in 48 h with COD reduction of 35% whereas in continuous reactor, same level of colour/COD reduction was obtained in 38 h residence time. No loss in decolourization ability of mycelial pellets was obtained when the reactor was operated continuously for more than 30 days.

Sammaiah Pallerla and Robert Chambers (1997) investigated the reduction of colour and adsorbable organic halides (AOX) from the kraft bleach plant effluents using a laboratory-scale fungal bioreactor. The experiments were carried out in fungal bioreactor, containing calcium-alginate entrapped white-rot fungus (*Trametes versicolor*) for continuous colour and AOX reduction. The influence of various operating parameters such as pH, residence time, inlet liquor concentration and fungal bead size on the bioreactor performance was investigated. Each continuous bioreactor study was carried out for a minimum period of 400 h using a 24 h residence time. From the results, it was found that the colour and AOX reduction were 69% (±6%) and 58% (±6%) using caustic stage effluent as bioreactor feed at a residence time of 1 day. Also the percentage reductions of colour and AOX ranging from 61% (±5%) to 72% (±2%) and 54% (±4%) to 49% (±2%), respectively, were observed using combined (caustic and acidic stages) effluent as bioreactor feed. Based on the scanning electron microscopy studies
they found that the immobilized mycelia were localized to a limited thickness near the outer surface of the polymer bead.

Nagarathnamma et al (1999) investigated decolorization and dechlorination of bleach plant effluent, especially extraction-stage effluent, by Rhizopus oryzae. It was found that the removal of colour, chemical oxygen demand, adsorable organic halide and extractable organic halide were 92 to 95%, 50%, 72% and 37% respectively in 24 h at temperatures of 25 to 45°C and a pH of 3 to 5 with addition of glucose at 1 g/liter. Also found that without addition of co-substrate the fungus removed up to 78% of the colour and monomeric chlorinated aromatic compounds were removed almost completely.

Basak (Kilic) Taseli and Gokcay (1999) studied the removal of organic halides and colour from pulp bleaching effluents of pulp and paper mill by using a fungal reactor. From the results it was found that the AOX and colour removal by Penicillium sp. was 50% in batch studies. Also the removal of AOX and colour was found to be around 70% in 7-8 hours contact time in up-flow column packed with glass wool.

Brian Van Driessel et al (2001) investigated the treatment of paper industry bleaching effluents in a Rotating Biological Contactor using *Coriolus versicolor*, a white-rot fungus and *Rhizomucorpusillus* strain RM7, a mucoralean fungus. The experiments were carried out for different initial colour intensities and hydraulic retention time. From the results, it was found that though decolorization was proportional to initial color intensity, its extent was significant only at the lower level. *R. pusillus* strain was removed 55% of AOX compared to *C. versicolor* (40%) and fungal treatment with both *R. pusillus* and *C. versicolor* rendered the effluent essentially nontoxic. Addition of glucose to decolorization media stimulated colour removal by *C. versicolor*, but not have any significant effect with *R. pusillus*. Ligninolytic
enzymes (manganese peroxidase and lactase) were only detected in effluent treated by *C. versicolor*. Also found that there are different kind of decoloring mechanisms involved between the white rot fungus (adsorption + biodegradation) and the mucoralean fungus (adsorption).

Esra Tarlan et al (2002) made a detail study to treat the effluent generated from wood-based pulp and paper industry. The experiments were carried out in batch reactor using mixed culture of algae which mainly composed of green algae (Chlorella, Chlorococcum, Chlamydomonas, Pandorina, Eudorina), a few diatoms (Nitzschia, Cyclotella), flagellates (Euglena) and some blue-green algae (Microcystis, Anabaena). The effect of different lighting, initial wastewater strength conditions and time were studied on removal of COD, AOX and colour and observed that the reduction of COD, colour and AOX were 58%, 84% and 80% respectively. Also the results showed that the mixed cultures of algae provide efficient COD, colour and AOX removal within a reasonable time period. No remarkable differences were observed in COD and colour removal when light intensity and wastewater strength were changed, while AOX removals were strongly affected.

Santos et al (2002) investigated the treatment of effluent from kraft bleach pulp and paper industry using white-rot fungus Pleurotus ostreatoroseu. The experiments were carried out in continuous turbulent-flow bioreactor at different dilutions and concentrations of glucose for removal of colour, total phenols and lignin/chlorolignin. From the results it was found that the average removal of colour and total phenols was 18.6% and 11.6% respectively, after the addition of glucose. The removal of colour, total phenols and lignin/chlorolignin was increased with increasing glucose concentration and found the maximum removal of colour, total phenols and lignin/chlorolignin was 19.4%, 9.4% and 44.5% respectively.
Yuancai Chen et al (2003) investigated the treatment of the effluent obtained from the different stage of process such as sulfite pulp Chlorination stage, alkaline extraction stage and hypochlorite stage bleaching effluents using coagulation–anaerobic acidification–aeration package reactor. From the results it was found that the COD, BOD, AOX and toxicity removals were 88.1%, 81.0%, 98.4% and 92.0% respectively, with 15 h hydraulic retention time. The toxicity and AOX were removed mainly through coagulation and anaerobic process, while the COD and BOD$_5$ were removed mainly through coagulation and aerobic process. Also found that the pretreatment of coagulation precipitation decreased the organic load, which decreased the treatment retention time and increased the stability of the system. In anaerobic process the outflow COD/AOX ratio were much larger than inflow, indicating that dechlorination and incomplete degradation of organic substance.

Correa (2003) studied the effect of increasing the concentration of 2,4,6-trichlorophenol (2,4,6-TCP) content in Elemental chlorine-free (ECF) bleaching effluent from a kraft mill on the degradative activity of bacterial communities present in an aerobic treatment system. The experiments were carried out in anaerobic lagoon under different hydraulic retention time and organic loading rate. The results showed that the continuous anaerobic lagoon yield the maximum BOD$_5$ and COD reduction of 90% and 40% respectively. At the same time, the anaerobic lagoon system showed a high ability to biodegrade 2, 4, 6-TCP up to 237 mg/l day. The tolerance of aerobic bacteria was observed up to 1.3 g/l of 2, 4, 6-TCP in continuous system.

Ragunathan et al (2004) studied the treatment of effluent from paper mill using Pleurotus spp., such as P. sajor-caju, P. platypus and P. citrinopileatus. From the results it was found that on the laboratory scale treatment P. sajorcaju removed the maximum of 66.7% colour after 6 days of the incubation whereas the removal of colour using P. platypus and P.
citrinopileatus were 59.1 and 55.1%. Also found that in the pilot scale treatment P. sajor-caju removed the colour and COD at maximum of 60.1% and 57.2% after 6 days whereas P. platypus and P. citrinopileatus removed the colour by 53.2% and 52.4%. Also the results revealed that the treatment of pulp and paper mill effluent by P. sajor-caju was better than P. platypus and P. citrinopileatus.

Indu Shekhar Thakur (2004) studied the removal of colour and adsorbable organic halogens in kraft pulp bleaching effluents using eight fungal and three bacterial strains. The results showed that the decolourization potency of *Paecilomyces* sp. was maximal (67%) on day 1 followed by *Phoma* sp. and *Paecilomyces varioti*. Among the various carbon sources used, *Paecilomyces* sp. reduced more than 80% colour and lignin in the presence of minimal salt medium and dextrose (0.2%, w/v), and there was an increase in biomass from 8.1 mg/ml to 12.8 mg/ml. In the batch reactor, it was found that *Pseudomonas aeruginosa*, removed 48% colour from the effluent after 1 day followed by *Acinetobacter calcoaceticus* (39%) and *Klebsiella pneumoniae* (25%). In a two stage sequential bioreactor, also found that the strain *Paecilomyces* sp. and *P. aeruginosa* were able to reduce 68 and 34% colour in 1 day. Also found that the reduction of adsorbable organic halogens (AOX) in effluent was determined by *Paecilomyces* sp. strain, however, bacterial strain PCP2 increased the content initially on day 1, which was readily degraded after 3 days by both fungus and bacterium in the sequential bioreactor.

Prabu et al (2005) studied the removal of colour and chlorinated phenol from paper mill effluent using a white rot fungus *Phanerochaete chrysosporium* isolated from soil samples enriched by continuous pulp and paper mill effluent irrigation. From the results it was found that the addition of carbon and nitrogen sources either alone or in combination had considerable effect on colour removal of effluent. The *Phanerochaete*
*Phanerochaete chrysosporium* removed 60.7% of colour with addition of glucose whereas 49.3% and 45.1% of colour removal was achieved with addition of fructose and starch. Also *Phanerochaete chrysosporium* strain responded more to ammonium sulphate and the colour removal was 67.4%, whereas 67% and 65% of colour removal was achieved with addition of diammonium phosphate and sodium nitrate, respectively. In addition, the results showed that combination of carbon and nitrogen sources caused maximum decolourization than their individual additions. The results revealed that the colour and COD reduction were 84% and 79% when addition of glucose and sodium nitrate sources as co-substrate. Also found that the chlorinated phenol was degraded by 91% by the fungus when 1% glucose was added as co-substrate.

Mahesh et al (2006) studied the treatment of black liquor from pulp and paper industry by electrochemical method. The experiments were carried out in a 2 dm$^3$ electrolytic batch reactor using iron plate electrodes. From the results it was found that the six-plate arrangement was found to be optimal. The maximum removal of chemical oxygen demand (80%) and colour (90%) was achieved at current density of 55.56 A/m$^2$ and neutral pH of 7. The chemical dissolution of iron was strongly influenced by pH and found that at the optimal current density, the iron electrode consumption was 31.27 g/m$^2$ h, with maximum COD removal. Also found that the addition of polyacrylamide (10 mg/dm$^3$) enhanced the COD removal rate with a very short treatment time with excellent sludge settleability. The specific energy consumption was reduced from 6.64 to 5.73kWh/kg of COD removed with the addition of NaCl (625 mg/dm$^3$). The post treatment of electrochemically treated wastewater was carried out using alum (360 mg/dm$^3$) along with 20 mg/dm$^3$ polyacrylamide (PAA). An overall COD removal of 91% and color removal of near 100% was achieved by electrochemical treatment followed by coagulation/flocculation.
Pratibha Singh and Indu Shekhar Thakur (2006) studied the removal of colour and other pollution parameters of combined effluent from pulp and paper mill by anaerobic treatment used by fungus (Paecilomyces sp.) and bacterial strain (Microbrevis luteum) separately in two steps bioreactor. From the results it was found that in anaerobic treatment, colour (70%), lignin (25%), COD (42%), AOX (15%) and phenol (39%) were reduced in 15 days. The anaerobically treated effluent was treated again using fungal strain, such as Paecilomyces sp., and bacterial strain such as Microbrevis luteum. From the results it was found that the reduction of colour, AOX, lignin, COD and phenol by Paecilomyces sp. were 95%, 67%, 86%, 88% and 63% where as M. luteum removed 76% of colour, 69% of lignin, 75% of COD, 82% of AOX and 93% of phenol. In addition it was found that significant increase in Biomass (27%) and change in pH (from pH 8 to 5) with fungal and bacterial treatment was achieved.

Ugurlu et al (2006) investigated the removal of chemical oxygen demand (COD), lignin and phenol from paper mill effluents using Three-Phase Three-Dimensional Electrode Reactor consisting of graphite electrode and powder-activated carbon (as working electrode). The experiments were carried out for removal of COD, lignin and phenol from paper mill effluent by varying the operating parameters such as voltages, electrolysis time, initial pH, activated carbon (AC), NaCl amount and airflow. From the results it was found that removal efficiency significantly depends on the applied cell voltage, airflow, time, salt amount and pH. For electrolyses under the conditions of 25.0V cell voltage, 5.0 min, in presence of air 2.0 minL\(^{-1}\), NaCl 5.0gL\(^{-1}\) at low pH and AC 20gL\(^{-1}\), it was found that the removal of COD, lignin and phenol from the paper mill effluent were almost higher than 90%. Also found that removal of lignin, phenol, BOD and COD increased with increasing cell voltage. Based on the results they suggest that the
electrochemical treatment could be used as an effective alternative method to treat paper mill effluents.

Moraes et al (2006) studied the treatment of black liquor generated from pulp and paper industry by bacteria azotobacter vinellandi and advanced oxidation processes. From the results it was found that the biological treatment with Azotobacter vinellandi could promote an effective decoloration and TOC reduction. Also found that the presence of Fe$^{3+}$ at high levels decrease the efficiency of siderophores in degrade the compounds present in the effluents. Among the different combined treatments, the best results were obtained with the photocatalytic pre-treatment.

Piyush Malaviya and Rathore (2007) studied the bioremediation of pulp and paper mill effluent by a fungal consortium isolated from the soil using a continuously aerated bench-top bioreactor. The experiments were carried out in a bench–top bioreactor that consisted of a 2-l glass aspirator bottle using immobilized two basidiomycetous fungi (Merulius aureus syn. Phlebia sp. and an unidentified genus) and a deuteromycetous fungus (Fusarium sambucinum Fuckel MTCC 3788). From the results it was found that the reduction of colour, lignin and COD of the effluent were 78.6%, 79.0% and 89.4% respectively after 4 days and also found that a major part of reductions of the above said parameters occurred within first 24 h of the treatment.

Ghoreishi and Haghighi (2007) designed a two-phase stage experiment to remove colour from pulp mill effluents via chemical and biological reactions in series. In the first phase, the chemical characterization of chromophores using the spectra of infrared (IR), ultraviolet (UV) and nuclear magnetic resonance (NMR) analyses was carried out. The results of chemical analyses indicated that the color-causing materials are mainly unsaturated compounds, possibly conjugated double bonds on aromatic rings.
The bench scale results of the first phase of the research demonstrated that the sodium borohydride (NaBH₄) reduction is a viable method for colour elimination with no sludge production and 97% colour removal was achieved in 24 h with reaction rate constant at 0.6 h⁻¹. Subsequently in the second phase of the experiments, the pilot plant of chemical and biological reactor system was investigated using two 20-l reactors operating in the batch mode having overall residence time of 6 days. In the first reactor, chemical hydrogenation with NaBH₄ was performed for 1 day and resulted in a colour and COD reduction by 97% and 35%. Also found that no significant change in reduction of total suspended solids and the chemically treated effluent was subjected to a biological oxidation reaction in the second reactor for further treatment with a residence time of 5 days. The results indicated that the significant decrease in BOD (99%), COD (92%), and TSS (97%) and consequently, a combined chemical and biological reaction system appears to effectively decrease the colour as well as BOD, COD and TSS. Also found that the economics of the pilot scale implementation of a NaBH₄ colour reduction treatment process for 97% colour removal was estimated to be in the range of 0.001 US dollar per liter of the most highly colored wastewater sample.

Bo Wang et al (2007) made a detail study to treat the wastewater from kraft cooking section of an agri-based paper mill by electrochemical oxidation process. The experiments were carried out by batch process using undivided cell of 200 ml capacity under constant temperature conditions. The superficial surface of the working electrode (3.2 cm×6 cm) was 19.2 cm² and 30 g dm⁻³ smashed catalyst was added into the system to form an oxidizing electrochemical reactor. The solution was constantly stirred at 200 rpm with a magnetic stirrer in order to maintain uniform concentration of the electrolyte solution. From the results it was found that under optimal operating conditions such as initial pH of 3, current density of 30mA/cm² and the
catalyst dose of 30 g dm$^{-3}$, the COD removal rate can reach 96.8% in 73 min. Also found that no significant increase in COD removal when current density exceeded to 50mAcm$^{-2}$.

Nataraj et al (2007) studied the pilot plant of a hybrid microfiltration (MF) and electrodialysis (ED) system to remove the colour and contaminants of paper industry wastewater. The experiments were carried out using microfiltration module comprising of ceramic membrane used at constant pressure as a pretreatment step for the ED and electrodialysis stack consisted of 11 cation-exchange and 10 anion-exchange membrane pairs. The tubular ceramic module was employed to pre-filter the wastewater at 60$^\circ$C and ambient temperature. From the results it was found that the combined hybrid process at the applied potential of 50V showed a low content of total dissolved solids (TDS) of 546 mg/l, conductivity of 0.61 mS/cm, and chemical oxygen demand (COD) of less than 20 mg/l and the hybrid MF/ED module recovered more than 90% of original wastewater. The proposed pilot plant was found to be more advantageous, since the ceramic membrane module used could withstand higher temperature of the discharged effluent and permeate was free from the suspended particles of colloidal nature. Also found that the hybrid process was more efficient than the single unit process.

Tsang et al (2007) studied the optimization of biological treatment of paper mill effluent in a sequencing batch reactor (SBR). The effect of operating parameters such as mixed liquor suspended solid (MLSS) concentration, volumetric exchange rate (VER), aeration time, temperature and daily operation cycle on biological treatment of the pulp and paper mill effluent were studied using four 4 sequencing batch reactors (SBR). From the results it was found that under optimal operating condition such as MLSS concentration of 4500 mg l$^{-1}$, VER of 50%, aeration time of 5 h per cycle and temperature of 30$^\circ$C, the chemical oxygen demand (COD) removal can reach
93.1±0.3%. Also found that the treatment performance of organic removal by the SBR system remained stable during the operation and the sludge settleability, in terms of sludge volume index (SVI), was improved to the healthy level (SVI = 52.7±1.3 ml g\(^{-1}\)).

Ahmad et al (2007) studied the optimization of coagulant dosages and pH to achieve highest removal of total suspended solids (TSS), lowest sludge volume index (SVI) and highest water recovery from pulp and paper mill wastewater using alum coupled with cationic polyacrylamide. The experiments were carried out in jar test apparatus using 500 ml wastewater samples. The coagulant and pH were varied in the range of 800–1200 mg/l and 6-8 and the coagulant aid of 1 mg/l polyacrylamide was added to the sample. From the results it was found that the coagulant dosage and pH are both significant terms to yield higher removal of TSS and minimum SVI and the coagulant dosage is not an important factor influencing water recovery. Also found that 99% of TSS removal, SVI of 37 mLg\(^{-1}\) and 82% of water recovery can be obtained at optimum conditions of 1045 mg L\(^{-1}\) coagulant dosage and 6.75 of pH, respectively. The quadratic models were developed using response surface method for TSS removal, SVI and water recovery.

Buzzini et al (2007) studied the performance of chemical and electrocoagulation processes followed by flocculation and sedimentation of an effluent from an UASB reactor treating simulated wastewater from an unbleached Kraft pulp mill. From the results it was found that the maximum removal of COD and colour in the electrocoagulation process with the aluminum electrode were 67% and 98% whereas the maximum removal efficiencies of COD and colour in the jar-test assays with aluminum sulfate without added polymer were 90% and 94% respectively. The highest COD removal rate provided by the aluminum electrode was 23 percentage lower than in the assay with aluminum sulfate. Similarly, the maximum removal of
COD and colour in the electrocoagulation process with the stainless-steel electrode were 82% and 84% whereas the maximum removal efficiencies of COD and colour in the jar-test assays with ferric chloride and without added polymer were 89% and 98% respectively. The removal efficiency was higher in the jar-test assays than in the electrocoagulation process, but the consumption of iron was higher in the assays with ferric chloride. Also found that in the combined process (UASB reactor plus electrocoagulation process), the maximum COD removal rates were 96% with the stainless-steel electrode and 94% with the aluminum electrode and no colour removal occurred in the UASB reactor; therefore, the maximum removal attained was 84% with the stainless steel and 95% with the aluminum electrode. In addition, the results confirmed the technical feasibility of the electrocoagulation process as a post-treatment following the UASB reactor for treating industrial paper and pulp wastewater.

Perng et al (2007) studied the treatment of paper mill wastewater using a pilot-scale electrocoagulation unit. The experiments were carried out by varying the operating parameters such as current density and hydraulic retention time (HRT). From the results it was found that the electrical conductivity decreased with increasing current density and HRT. Also found that under the optimal operating conditions (a current density of 106.7 Am$^{-2}$, and an HRT of 3.25 min) the electrical conductivity, suspended solids, chemical oxygen demand and colour were found to be 25.4%, 97.14%, 76.47% and 70.09% respectively.

Wang et al (2007) studied the treatment of paper mill wastewater by electrochemical method. The experiments were carried out using three-dimensional electrodes. From the results it was found that around 75% of chemical oxygen demand and color removal was achieved at current density of 167 mAcm$^{-2}$, pH of 11 and electrolyte concentration of 15 g/l.
Mansour et al (2007) made a detail study on treatment of wastewater from paper industry. The experiments were carried out in both batch and continuous modes by using electrodes and a flotation unit. The electrodes were made up of titanium coated with ruthenium oxide as anode and stainless steel as cathode. The voltage was varied between 7 to 9 volts and the current density was varied and not fixed. The batch mode aims to optimize coagulant concentration, pH and current density at fixed electrolysis time (20 minutes). Continuous mode aims to optimize the residence time. From the results it was found that the removal efficiency of suspended solids in both the cases was more than 95%.

Abhay Raj et al (2007) studied treatment of pulp and paper mill combined effluent using three lignin-degrading bacterial strains such as Paenibacillus sp., Aneurinibacillus aneurinilyticus and Bacillus sp. The experiments were carried out in cotton-plugged erlenmeyer conical flasks with mineral salt (MS) at pH 7.6 and the flasks were incubated at 30°C on a rotary shaker (120 rpm) in dark conditions for six days. From the results it was found that all three bacterial strains effectively reduced colour (39–61%), lignin (28–53%), biochemical oxygen demand (BOD) (65–82%), chemical oxygen demand (COD) (52–78%) and total phenol (64–77%) within six days of incubation. However, the highest reduction in colour (61%), lignin (53%), BOD (82%) and COD (78%) was recorded by Bacillus sp. while, maximum reduction in total phenol (77%) was recorded with Paenibacillus sp. Also found that the significant reduction in colour and lignin content by these bacterial strains after two days of incubation, indicating that bacterium initially utilized growth supportive substrates and subsequently chromophoric compounds thereby reducing lignin content and colour in the effluent. The degradation of lignin present in the effluent was identified in extracts of treated samples by Paenibacillus sp were t-cinnamic acid and ferulic acid,
while 3-hydroxy-4-methoxyphenol, vanillic acid and vanillin acid by A. aneurinilyticus and gallic acid and ferulic acid by Bacillus sp., respectively.

Ebru Cokay Catalkaya et al (2007) studied the treatment of pulp mill effluent containing toxic chemicals by different advanced oxidation processes (AOPs) consisting of treatments by hydrogen peroxide, Fenton’s reagent ($\text{H}_2\text{O}_2/\text{Fe}^{2+}$), UV, UV/$\text{H}_2\text{O}_2$, photo-Fenton (UV/$\text{H}_2\text{O}_2/\text{Fe}^{2+}$), ozonation and peroxone (ozone/$\text{H}_2\text{O}_2$). The experiments were carried out by varying the operating parameters such as initial pH, oxidant and catalyst concentrations for removal of colour, TOC and AOX. From the results it was found that the hydrogen peroxide treatment alone resulted in very low TOC (5.1%), AOX (34%) and color (24%) removals at an extreme pH of 11, which were not satisfactory. Fenton’s reagent ($\text{H}_2\text{O}_2/\text{Fe}^{2+}$) yielded very high colour (85%), TOC (88%) and AOX (89%) removals within 30 min at a pH of 5. UV treatment alone is an ineffective treatment method yielding unacceptably low colour, TOC and AOX removals. Performance of the UV/$\text{H}_2\text{O}_2$ treatment was also unsatisfactory yielding low percent removals of colour, TOC and AOX. Percent removals obtained with the photo-Fenton treatment were comparable with those obtained with the Fenton’s reagent. Photo-Fenton treatment yielded high TOC (85%), colour (82%) and AOX (93%) removals within 5 min indicating the effectiveness of this treatment. Oxidation rates increased considerably due to contribution of UV radiation to the Fenton treatment. Ozone treatment alone was not as effective as the treatment by the Fenton’s reagent yielding low TOC and AOX removals. Peroxone treatment improved the AOX removal, however reduced the colour and TOC removals as compared to the ozone treatment alone. However, photo-Fenton treatment seems to be more advantageous requiring much less reaction times and therefore smaller reactor volumes as compared to the Fenton treatment.
Ugurlu et al (2008) studied the removal of lignin and phenol from paper mill effluents by electrocoagulation. The experiments were carried out at various current intensities by using different electrodes and at various electrolysis times for removal of lignin, phenol, chemical oxygen demand and biological oxygen demand. From the results it was observed that the experiments carried out at 12 V, an electrolysis time of 2 min and a current intensity of 77.13 mA were sufficient for the removal of pollutants with each electrode. Also found that the removal of lignin, phenol, BOD and COD using an Al electrode were 80%, 98%, 70% and 75% respectively, after 7.5 min whereas the iron electrode removes 92%, 93%, 80% and 55% of lignin, phenol, BOD and COD respectively. The removal of lignin, phenol, BOD and COD increased with increasing current intensity. Based on the results they suggest that the electrocoagulation treatment could be used as an effective alternative method to treat paper mill effluents.

Belem et al (2008) studied the degradation of organic matter and removal of colour by contacting white rot fungi Pleurotus sajor caju and Pleurotus ostreatus with effluents from a kraft bleach plant after treatment by an activated sludge process. The experiments were carried out in 180 ml batch reactors and the samples were incubated at 25ºC and 120±10 rpm through 14 days. From the results it was found that the P. sajor caju and P. ostreatus strain removes the 76 and 43.9% of COD after 14 days of treatment of final effluent with glucose.

Heikki Sarkka et al (2008) studied the electrochemical inactivation of three aerobic bacteria species (Deinococcus geothermalis, Pseudoxanthomonas taiwanensis and Meiothermus silvanus) living in paper mill circulating waters with mixed metal oxide electrode. The effect of parameters such as current density and initial pH or chloride concentration of synthetic paper machine water on the inactivation efficiency were
investigated. From the results it was found that the increasing current density and initial chloride concentration of synthetic paper machine water increased the inactivation rate but change of pH value did not have significant influence on the inactivation rate. Also found that inactivation was mainly due to the electrochemically generated chlorine/hypochlorite. Electrochemical oxidation showed good performance for inactivation these primary biofilm forming bacteria species with improved current efficiency by higher initial chloride concentrations.

Patel et al (2008) studied the treatment of bleaching effluent by electrochemical method. The experiments were carried out in a batch mode for removal of pentachlorophenol (PCP), colour and COD. From the results it was found that 10 mg/l of PCP in water was removed almost completely in less than 10 min at a current density of 6 mAcm$^{-2}$ in the presence of 1000 mg/l NaCl serving as an electrolyte and source of chloride ions. The initial rate of PCP removal was found to decrease at alkaline pH (9.3) as compared to that at acidic pH (5.5). PCP removal in neutralized raw pulp bleach effluent (containing 1830 mg/l of chloride) was very slow and incomplete even after 2 h of electrochemical treatment at a current density of 15 mAcm$^{-2}$. Various pretreatments of raw bleach effluent such as, alkaline sulfide using sodium sulfide, alkaline reduction using ferrous sulfate and coagulation using potash alum were evaluated. Electrochemical treatment of potash alum pretreated effluent (spiked with PCP) could achieve more than 90% removal of initial colour, COD and PCP in less than 1 h.

Shail Singh et al (2008) investigated the biotransformation of pentachlorophenol and paper mill effluent decolorisation by the bacterial strains in a mixed culture (Bacillus sp. and Serratia marcescens). The study revealed that it has decreased high load of BOD, COD, TS, TDS, TSS, sulphate, phosphate, total nitrogen, total phenols, metals and different salts
(i.e. chloride, sodium, nitrate, potassium) at 168 h incubation period. From the results it was found that the mixed culture degrade the pentachlorophenol (PCP) up to 94% with 1% glucose and 0.5% peptone (w/v) at 30 ± 1°C, pH 8.0 ± 0.2 at 120 rpm in 168 h incubation period. Also found that the simultaneous release of chloride ion up to 1200 mg/l at 168 h emphasized the bacterial dechlorination in the medium. Also found that the paper mill effluent degradation was supported by decline in pH, AOX, colour, DO, BOD, COD and PCP. The analysis of paper mill effluent degradation products by GC–MS analysis revealed the formation of low molecular weight compound like 2-chlorophenol (RT = 3.8 min) and tetrachlorohydroquinone (RT = 11.86 min) from PCP extracted degraded sample.

Marcela Boroski et al (2008) studied the effect of operational parameters on electrocoagulation–flotation process followed by photocatalysis applied to the decontamination of water effluents from cellulose and paper factories. The experiments were carried out by using aluminium and iron electrodes. From the results it was found that under optimum condition (time = 30 min, current density = 153Am\(^{-2}\) and pH= 6.0) the COD values, UV–vis absorbance and turbidity were decreased. The UV photocatalysis (mercury lamps) TiO\(_2\) was employed subsequently and the favourable operational conditions were found to be 0.25 g/l of the catalyst and solution pH of 3. Also found that by employing the UV/TiO\(_2\)/H\(_2\)O\(_2\) system, the COD reduction was 88% compared to pre-treated effluents. The salt concentration on electrocoagulation (iron electrodes) showed that the electrolysis duration can be reduced from 30 to 10 min by the addition of 5.0 gL\(^{-1}\) of NaCl. Also found that the biodegradability index (BOD/COD) increased from 0.15 to 0.48 (after Electrocoagulation) and 0.15 to 0.89 (after Electrocoagulation /photocatalysis irradiated for 6 h). Based on the results they suggest that the electrocoagulation treatment followed by photocatalysis could be used as an effective alternative method to treat paper mill effluents.
Muhammad Afzal et al (2008) investigated a combined biological, coagulation and filtration treatment process at pilot scale for wastewater treatment from paper and pulp industry. From the results, it was found that the biological treatment by fed batch reactor (FBR) followed by coagulation and sand filtration (SF) resulted in a total COD and BOD reduction of 93% and 96.5%, respectively. Also found that a significant reduction in both COD (90%) and BOD (92%) was observed by sequencing batch reactor (SBR) process followed by coagulation and filtration. However, the untreated effluent was found to be toxic, whereas the treated effluents by either of the above two processes were found to be non-toxic when exposed to the fish for 72 h. In addition it was found that the pilot scale application of the combined treatments to pulp and paper industry effluents exhibit promising large-scale perspective.

Sittichok Khansorthong et al (2009) studied the treatment of wastewater from pulp and paper industry by electrochemical technique. The experiments were carried out in both batch and continuous mode using iron electrodes. The effect of key parameters including the type of polyelectrolyte, current density, initial pH of the wastewater and the circulating flow rate of wastewater in the reactor were studied to achieve a higher removal capacity. From the results it was found that the polyelectrolytes such as sodium silicate, calcium carbonate and polyacrylamide had no effect on pollutant removal. Under the optimal experimental conditions (current density = 20.7A/m², initial pH = 7.58, circulating flow = 2.6 l/min and operating time = 45min ), the removal of colour, COD, BOD, TSS and TDS were found to be 97%, 87.8%, 91.2%, 89.8% and 37.5% respectively. Also found that the pH of the treated wastewater was 8.84 and the energy consumption and operating costs were found to be 1.2 kWh/m³ and 0.29 USD/m³, respectively. The kinetics of the rate of colour and COD removal were directly proportional to the applied current density. Also found that in continuous process, using the same
optimum batch process conditions, the system reached its steady state condition within 2.15 h and, at the higher and less efficient feed rate of wastewater into the electrochemical reactor of 66.67 ml/min, all properties of the treated wastewater, including colour, COD, TDS and TSS, except BOD$_5$ were acceptable to discharge into the environment. In addition, the colour of the treated wastewater was not objectionable, its pH was around 8.05 and the residual iron concentration was lower than 0.4 mg/l.

Jain et al (2009) studied the removal of colour from combined effluents (bleach plant and chemical recovery sections) generated from pulp and paper mill effluent using baggase fly ash. The experiments were carried out by varying the parameters such as initial effluent concentration, solution pH, adsorbent dose, contact time and particle size. From the results it was found that the maximum removal of colour (86%) was achieved in 60 min contact time and 2 g/l baggase fly ash. The percentage removal of colour increased with increasing adsorbent doses and as such removal increased with decreasing size of the adsorbent material. Also found that the Langmuir and Freundlich isotherm models were satisfactorily fit with experimental data.

Cesar Lagos et al (2009) studied the colour removal and aromatic compound behavior in kraft mill effluents (pulp bleaching) during tertiary treatment by Eichhornia crassipes. From the results it was found that the organic matter removal by E. crassipes ranged between 46 and 75%, whereas total phenolic compound removal was between 11 and 17%. Also found that the assays were performed with 50% and 10% kraft mill effluent under experimental conditions and the E. crassipes removed the colour around 8.5% and 23.6%. In addition, it was found that the poly R-478, used as a model compound to evaluate the aromatic behavior in the system, presented similar results in terms of colour removal with kraft mill effluent and under
experimental conditions, E. crassipes biomass was missing during the fall season.

Freitas et al (2009) investigated the efficiency of the biological treatment of an effluent derived from the secondary treatment of a bleached kraft pulp mill processing using fungus. The experiments were carried out in a batch reactor using four funguses such as Pleurotus sajor caju, Phanerochaete chrysosporium, Trametes versicolor and Rhizopus oryzae. From the results it was found that among the four species P. sajor caju and R. oryzae were the most effective in the biodegradation of organic compounds present in the effluent, being responsible for the reduction of relative absorbance (25–46% at 250 nm and 72–74% at 465 nm) and of chemical oxygen demand levels (74 to 81%) after 10 days of incubation. Laccase (Lac), lignin (LiP) and manganese peroxidases (MnP) expression varied among fungal species, where Lac and LiP activities were correlated with the degradation of organic compounds in the effluent treated with P. sajor caju. The first two axes of a principal component analysis explained 88.9% of the total variation among sub-samples treated with the four fungus species, after different incubation periods. All the variables measured contributed positively to the first component except for the MnP enzyme activity which was the only variable contributing negatively to the first component. Absorbances at 465 nm, LiP and Lac enzyme activities were the variables with more weight on the second component. P. sajor caju revealed to be the only species able to perform the biological treatment without promoting an increment in the toxicity of the effluent to the Vibrio fischeri.

Zaied et al (2009) studied the treatment of black liquor from paper industry using electrocoagulation method. The experiments were carried out using sacrificial electrodes such as aluminum and iron at room temperature and at a constant magnetic stirring speed of 200 rpm. The removal of COD,
polyphenols and colour was investigated by varying the operational parameters such as current densities (1.7 to 16.7mAcm$^{-2}$), electrolysis times (0 to 60 min) and initial pH (2 to 12). From the results it was found that under the optimal experimental conditions (initial pH 7, $t = 50$ min and $J=14$mAcm$^{-2}$), the removal of COD, polyphenols and colour using an Al electrode were 98%, 92% and 99% respectively. Also found that the removal of COD, polyphenol and colour increased with increasing current intensity. It was found that the removal efficiency using Al electrode was higher than Fe electrode. Based on the results, they suggested that electrocoagulation method could be used as effective alternative method for treatment of paper mill effluents.

Parama Kalyani et al (2009) investigated the decolorization and COD reduction of paper industrial effluent using electro-coagulation process. The influence of electrolysis time, applied charge density, electrolyte pH and supporting electrolyte on electrocoagulation efficiency for the treatment of pulp and paper industrial effluent were studied by using aluminium and mild steel electrodes. Three types of experiments such as electro-coagulation, sequential batch reactor and integrated process combining electro-coagulation followed by sequential batch reactor were carried out to treat the effluent. From the results it was found that the maximum colour and COD removal efficiencies were recorded as 92%, 95% and 84%, 89% for mild steel and aluminum electrode respectively. Also found that the electro-coagulation process increased the biodegradability from 0.2 to 0.4 within 10 min of process time. The performance of biochemical treatment of pulp and paper effluent has been increased significantly when electrocoagulation is combined with the sequential biological reactor. Also the electro-coagulation was modeled using adsorption isotherm and it has been observed from the present investigation that Langmuir and Radke–Prausnitz isotherm models match satisfactorily with the experimental observations.
Anjali Singhal et al (2009) made a detail study on decolourization and detoxification of pulping stage effluent from pulp and paper mill by Cryptococcus sp (PF7). The experiments were carried out in shake flask and the parameters such as temperature, shaking Condition, dextrose, tryptone, inoculum size, pH and duration were optimized by Taguchi approach. From the results it was found that the three fungal strains were isolated from sediments of pulp and paper mill in which PF7 reduced colour (27%) and lignin content (24%) of the effluent on 5th day. Also found that at optimized conditions (temperature (30–35 °C); shaking condition (125 rpm); dextrose (1.0% w/v); tryptone (0.1% w/v); inoculum size (7.5% w/v); pH (5) and duration (24 h)) the reduction of colour and lignin were 50–53% and 35–40%, respectively. The variation in pH from 5 to 6 had most significant effect on decolourization (72%) while variation in temperature from 30°C to 35°C had no effect on the process. The treated effluent was further evaluated for toxicity by alkaline single cell (comet) gel electrophoresis (SCGE) assay using Saccharomyces cerevisiae as model organism and 45% of reduction was observed.

Anjali Singhal et al (2009) studied the decolourization and detoxification of pulp and paper mill effluent by Emericella nidulans var. nidulans (anamorph: Aspergillus nidulans) (PF4). The experiments were carried out in shake flask and the parameters such as temperature, rpm, dextrose, tryptone, inoculum size, pH and duration were optimized by Taguchi method. From the results it was found that the four fungal strains were isolated from sediments of pulp and paper mill in which PF4 reduced colour (30%) and lignin content (24%) of the effluent on 3rd day. Also found that at optimized conditions (temperature (30–35 °C); rpm (125 rpm); dextrose (0.25%); tryptone (0.1%); inoculum size (7.5%); pH (5) and duration (24 h)) the reduction of colour and lignin were 66.66% and 37%, respectively. The Optimization improved the colour and lignin reduction potential of E.
*nidulans* var. *nidulans* by 31%. The variation in pH from 5 to 6 had most significant effect on decolourization (71%) while variation in temperature from 30°C to 35°C had no effect on the process. Also found that the effluent was genotoxic in nature and treatment by *Emericella nidulans* var. *nidulans* at optimum conditions reduced the genotoxicity by 60%.

De los Santos Ramos et al (2009) studied the treatment of pulp and paper mill effluents by combination of chemical precipitation and ozonation method. The experiments were carried out using the diluted wastewater (1:10), which contains considerable amounts of high-molecular-weight pollutants and it was pre-treated separately by precipitation with sulfuric acid (97.1%) at the initial pH 1 and 3, then by the simple ozonation at the pH 1, 3, 8 and 12 in order to reduce colour, decompose dissolved contaminants and increase the biodegradability (BOD<sub>5</sub>/COD) of the final compounds composition. Also the effect of the precipitation conditions and of the ozonation time on the decolorization kinetics and on the composition of the ozonation products has been evaluated. From the results it was found that the reduction of COD and colour were found to be 77 and 96.1%, respectively. Also found that the various by products such as fumaric, maleic, malonic and formic acids were formed from filtered residual water at the pH 1, 3, 8 and 12 with ozonation during 25 min. The precipitation pH has significant effect on the efficiency of sulfolignin formation as well as on the lignin decolorization kinetics. The biodegradability of the lignin decomposition products was increased in ozonation at the four pHs (1, 3, 8 and 12) from 0.24 to 0.29 during 25 min.

Yuzhong Zhang et al (2009) studied the performance of integrated membrane process which consists of the membrane bioreactor (MBR), the continuous membrane filtration (CMF) and the reverse osmosis (RO) on pilot scale for treatment of paper mill wastewater. The discharged water from the
first sedimentation tank was treated with the anoxic/aerobic/MBR membrane system to eliminate NH$_3$–N. Although the permeate met the quality standards of feed for RO system, the CMF unit before RO system is used in this integrated system in order to keep RO system operation safely. In this system a low-pressure RO unit with the form of anti-fouling spiral-wound membrane was used to purify the influent from CMF unit. From the results it was found that the recovery of water in RO system was 65%. Also found that the RO permeate could meet the whole standards of process water of paper mill. The conductivity, COD, turbidity and chroma of RO permeate were found to be less than 200 mS/cm, 15 mg/L, 0.1 NTU and 15 PCU, respectively.

Ashtoukhy et al (2009) studied the treatment of combined effluent from Rakta’s Pulp and Paper Company where rice straw is used to produce paper pulp. The experiments were carried out in a cylindrical agitated vessel lined with lead sheet as anode while a concentric cylindrical stainless steel sheet screen was placed as a cathode. The removal of colour and COD was investigated by varying the parameters such as current density, pH, NaCl concentration, impeller rotational speed and temperature. From the results it was found that the decolorization and COD percentage removal increased with increasing sodium chloride concentration, current density, impeller rotational speed and temperature. The reduction of COD and colour was varied from 41 to 90.5% and 53 to 100% depending on the operating conditions. Also found that the energy consumption decreased with increasing impeller rotational speed and NaCl concentration whereas it increased with increasing current density and the energy consumption was varied from 4 to 29 kWh/m$^3$ depending on the operating conditions.

Ram Chandra et al (2009) studied the treatment of pulp and paper mill bleaching effluent by pentachlorophenol (PCP) degrading bacterial strains such as Bacillus cereus (ITRC-S$_6$) and Serratia marcescens (ITRC-S$_7$).
The experiments were performed in Erlenmeyer flask containing 100 ml sterilized effluent samples supplemented with 1.0% glucose and 0.5% peptone (w/v) as co-substrates. The flasks were inoculated with 1 ml of bacterial culture having an inoculum’s sizes (CFU/ml) of 6.0×10^5 and 2.5×10^3 for ITRC-S_6 and ITRC-S_7 respectively. Mixed culture of two bacterial strains (1:1) was also inoculated and the flasks were incubated at 30^0C ± 1^0C at 120 rpm for 168 h. From the results it was found that both bacterial strains effectively reduced colour (45–52%), lignin (30–42%), BOD (40–70%), COD (50–60%), total phenol (32–40%) and PCP (85–90%) within 168 h of incubation. Also the highest reduction of colour (62%), lignin (54%), BOD (70%), COD (90%), total phenol (90%) and PCP (100%) was recorded by mixed culture treatment. The bacterial mechanism for the degradation of pulp and paper mill effluent was explained by an increase in the cells biomass. The GC-MS analysis of ethyl acetateextractable compounds from treated pulp paper mill effluent reinforces the bacterium capability for the degradation of lignin and pentachlorophenol, as many aromatic compounds such as 2-chlorophenol, 2, 4, 6-trichlorophenol and tetrachlorohydroquinone, 6-chlorohydroxyquinol and tetrachlorohydroquinone detected which were not present in the untreated effluent.

Kati Eskelinen et al (2010) studied the treatment of bleaching effluents from pulp and paper mill using individual physico-chemical treatments like chemical precipitation and electrochemical treatment. Advanced oxidation processes (AOPs) such as ultrasonic irradiation in combination with Fenton-like oxidation (Fe^{3+}/H_2O_2) or photo-Fenton degradation (Fe^{2+}/H_2O_2/UV) were also separately used for treatment of bleaching effluent. The effects of operating parameters such as pH and oxidant’s dose on the removal of organic compounds were investigated in terms of COD removal. From the results it was found that among the various treatment techniques, the chemical precipitation method removes the COD up
to 90%. Also found that each individual treatment could improve the treatability of bleaching wastewater, neither of them could generate treated effluents that met the strict requirement of COD limit of less than 200 mg/L. Based on the results, they suggested that the integration of physico-chemical and biological process could be used as alternative method to complete degradation of compounds in the samples prior to their discharge.

Beril Gonder et al (2011) studied the application of two-step nanofiltration (NF) process in the purification of biologically treated pulp and paper wastewater for the purpose of reuse. The experiments were carried out using FMNP010 membrane and the membrane fouling was minimized by optimizing the operating conditions such as pH, temperature, transmembrane pressure and volume reduction factor (VRF) using Taguchi experimental design method. From the results it was found that the transmembrane pressure has significant effect on membrane fouling and also found that under the optimal conditions, 91% chemical oxygen demand, 92% total hardness and 98% sulphate removal were achieved using FMNP010 membrane. Also found that the water produced by two step NF treatment of biologically treated pulp and paper industry meets the quality of actual process water.

Mikko Vepsalainen et al (2011) studied the effect of electrocoagulation treatment on toxic pollutant removal from pulp mill effluents. The experiments were carried out for removal of toxic pollutant from pulp mill effluent by varying the operating parameters such as current density, initial pH and treatment time using iron as working electrodes. From the results it was found that the removal of 97% resin acid was achieved by electrocoagulation followed by filtration with an initial pH of 5, a treatment time of 60s and an initial concentration of 125 mg/l. Also found that the removal of 72-97% copper was achieved by electrocoagulation with a current of 2A and a treatment time of 60s. Also the model was developed from the
results using statistical experimental design. Based on the results they suggest that the electrocoagulation combined with separation technologies such as filtration, sedimentation or flotation could be used for toxic pollutant removal from pulp mill effluents.

Mikko Vepsalainen et al (2011) studied the precipitation of dissolved sulphide ions from pulp and paper mill wastewaters by electrocoagulation. The experiments were carried out in electrochemical cell using iron as working electrodes. From the results it was found that removal of 88% dissolved sulphides and 40% phosphorus was achieved with an applied current charge of 60 C/L. Based on the results they suggest that the electrocoagulation treatment could be used for precipitate dissolved sulphides from pulp and paper mill wastewaters.

Reza Katal and Hassan Pahlavanzadeh (2011) studied the performance of electrocoagulation (EC) technique in the treatment of paper mill wastewater using different combination of aluminum (Al) and iron (Fe) electrodes. The influence of variables such as current density, type of electrode material, electrolysis time and wastewater pH and conductivity on the removal of colour, phenol and COD were studied using sacrificial electrodes. From the results it was found that the reduction of removal efficiency is considerable when pH<5 or pH>7. Also found that the electrocoagulation process was most effective at low temperature and increasing temperature from 20 to 60°C, reduce removal efficiency more than 20%.

Salim Zodi et al (2011) studied the treatment of paper mill wastewater collected at the outlet of the clarifier located downstream of the biological treatment using electrocoagulation method. The experiments were carried out using sacrificial electrodes such as aluminum and iron. Removal of chemical oxygen demand and dissolved organic carbon from wastewater
was investigated at two different current densities (100 and 150 mA cm$^{-2}$) by using different electrodes (Al and Fe) and at electrolysis time of 90 min. From the results it was found that the dissolved organic carbon removal ranged between 24% and 46%, and chemical oxygen demand removal ranged between 32% and 68%. Based on the results they suggested that the electrocoagulation treatment could be very effective method for treatment of paper mill wastewaters after biological treatment.

Tingzhi Liu et al (2011) studied the treatment of poplar alkaline peroxide mechanical pulping (APMP) effluent using Aspergillus niger. The experiments were carried out in a batch mode using Aspergillus niger. From the results it was found that under the optimal conditions (3% inoculum, pH 6, shaking at 160 rpm, 60–72 h, and 30°C), the Aspergillus niger was able to remove about 97% of the methyl tertiary butyl ether (MTBE) extractives, and 60%, 77% and 43% of the chemical oxygen demand, turbidity and colour.

Yogendra Prakash Singh et al (2011) studied the treatment of pulp and paper mill effluent using Enterobacter sp. From the results it was found that the pollution reduction was significantly affected by various parameters including the amount of inoculum size, rate of agitation, the reaction temperature and the duration of treatment. Also found that COD/BOD load could rapidly be reduced to 80%; lignin to 73% and colour to 82% within 16 h, using a 10% inoculum size, agitation at 200 rpm and temperature at 35°C.

Diana Botia et al (2012) studied the treatment of pulp mill bleaching effluent using biological–photocatalytic coupled system. The biological pre-treatment experiment was carried out using a fungus, Trametes pubescens, immobilized on polyurethane foam and then it was exposed to a photocatalytic treatment. The catalyst characterization was also carried out by means of X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM). From the results it was found that the overall biological–
photocatalytic coupled system achieved degradation of 96% of initial total organic carbon (TOC), 97% of 2-chlorophenol (2-CP), 90% of 2,4-dichlorophenol (2,4-CP) and 99% of 2,4,6-trichlorophenol (2,4,6- TCP).

Ram Chandra and Rachna Singh (2012) studied the decolourisation and detoxification of rayon grade pulp and paper mill effluent by mixed culture of three bacterial strains (Pseudochrobactrum glaciale, Providencia rettgeri and Pantoea sp.) isolated from pulp and paper mill effluent polluted site. From the results it was found that the removal of colour, chemical oxygen demand and biological oxygen demand by mixed culture were found to be 96.02%, 91% and 92.59% within 216 h of the incubation period. The maximum enzyme activity for lignin peroxidase (LiP), manganese peroxidase (MnP) and laccase were recorded at 48, 72 and 144 h of the incubation period, respectively. Also found that the toxicity assessment of the pulp and paper mill effluent on Vicia faba L. showed 40% reduction after bacterial treatment.

Qu et al (2012) studied the treatment of pulp and paper effluent using integrated thermophilic submerged aerobic membrane bioreactor (TSAMBR) and electrochemical oxidation (EO) method. From the results it was found that under the organic loading rate of 2.76-3.98 kgCOD/m³d and hydraulic retention time of 1.1 d, the removal of chemical oxygen demand was found to be 88.6-92.3%. Also found that after 6 h electro oxidation, a complete decolourisation was achieved and the COD removal efficiency was increased to 96.2–98.2%. Based on the results they suggested that the integrated TSAMBR-EO technology could be used as effective method for treatment of pulp and paper effluent.
2.2 TREATMENT OF EGG PROCESSING INDUSTRY EFFLUENT

Harris and Moats (1975) studied a laboratory method involving pH adjustment and heating to recover egg solids from egg processing wastewater. From the results it was found that the removal of biochemical oxygen demand and chemical oxygen demand were 90 and 97% respectively. Also found that the recovered solids contained a high concentration of protein, which make them a potentially valuable by-product for use in livestock feeds.

Bough (1975) studied the treatment of wastewater generated from egg breaking section using 100 to 200 mg/l Chitosan and 2 to 20 mg/l Betz polymers. From the results it was found that the removal of total solids and chemical oxygen demand were varied from 70 to 90% and 55 to 75%, respectively, depends on the process conditions. Also found that the yield of dry-coagulated solids approximately 5.4 kg/3,780 L of treated wastewater and the estimated polymer cost was $0.80/3,780 L.

Bulley (1976) studied the recovery of by-products from egg processing wastewater using 200 mg/l aluminum sulfate. From the results it was found that the coagulation treatment techniques removed 38 to 92% and 80 to 89% of the total solids and BOD respectively depends on the quantity of coagulant added. Also found that the recovered solids were not acceptable for use in livestock feed because of the presence of alum. Furthermore, removal efficiency was strongly dependent on the concentration of solids in the wastewater streams.

Xu et al (2001) studied the treatment of egg processing wastewater using different coagulants such as lignosulfonate, bentonite, carboxymethylcellulose and ferric chloride. From the results it was found that the removal of chemical oxygen demand, turbidity, total solids and protein &
fat recoveries were over 90%, 97%, 95% and 95% respectively, for simulated and industrial wastewater for all coagulants. The optimal coagulant concentration for maximum by-product recovery depended on initial wastewater concentrations of protein, total solids and fats. The dried by-products contained high concentrations of protein (30 to 50%) and fats (30 to 40%). Also found that the relative protein digestibilities of each recovered solid (carboxymethycellulose, lignosulfonate, bentonite and ferric chloride) and corn meal relative to a liquid whole egg standard were approximately 80%, 90%, 60%, 30% and 56% respectively.

2.3 TREATMENT OF RICE MILL EFFLUENT

Rajesh et al (1999) studied the treatment of rice mill wastewater using two stage upflow anaerobic sludge blanket (UASB) bioreactor. The experiments were carried out in a sequence of acidification and methanogenic process. From the results it was found that the maximum volatile fatty acid yield was 0.75 mg (as acetic acid) per mg of COD consumed at a flow rate of 25 ml/min and hydraulic retention time (HRT) of 1 hr for acidification process. Also found that the removal of BOD and COD were 89 and 78% respectively at loading rate of 3 kg COD m\(^3\) d\(^{-1}\) and HRT of 30 hrs. The gas yield in methanogenic reactor was 0.56 lits per kg COD consumed which contains 62% v/v methane.

Manogari et al (2008) studied the treatment of rice mill wastewater using immobilized pseudomonas sp. cells and the experiments were carried out in a packed bed reactor. From the results it was found that the removal of COD and BOD were 86.44 and 55.34% respectively after 24 hours. Also found that the electrical conductivity, salinity and total dissolved solids decreased to a considerable extent. Also found that the quality of the rice mill effluent was improved by varying cell loading (1.7 - 2.2 mg cells per bead).
Manaswini Behera et al (2010) studied the performance of microbial fuel cells (MFC) made of earthen pot and a proton exchange membrane (PEM) for treatment of rice mill wastewater at feed pH of 8.0, 7.0 and 6.0. The comparison of earthen pot MFC and proton exchange membrane MFC were also studied. From the results it was found that the maximum chemical oxygen demand removals were 96.5%, 92.6% and 87% for MFC-1, MFC-2 and MFC-3 respectively at feed pH of 8. Also found that the lignin removal was 84%, 79%, and 77% and the phenol removal was 81%, 77% and 76% in MFC-1, MFC-2, and MFC-3, respectively. More effective treatment of rice mill wastewater and higher energy recovery was achieved by earthen pot MFC as compared to MFC incorporated with PEM.

2.4 TREATMENT OF INDUSTRIAL EFFLUENT BY ELECTROCOAGULATION

Pouet and Grasmick (1995) studied the treatment of municipal wastewater by electrocoagulation in combination with dissolved air flotation process (DAF). From the results it was found that the removal of suspended solids, turbidity and COD were 85%, 90% and 70%. The combined DAF and electrocoagulation process was found to be advantageous, but it could result in uneconomical process due to high initial capital and operating cost of DAF together with electrocoagulation. Based on the observation they made an attempt to treat the municipal wastewater keeping in view of the drawbacks of high sludge production and high capital and operating cost by employing a simple experimental process of electrocoagulation followed by flocculation and sedimentation, with the in situ generated coagulant without adding any chemicals.

Chen et al (2000) studied the treatment of restaurant wastewater by electrocoagulation followed by sedimentation for 2 hours. From the results it
was found that the removal of suspended solids with the insitu-generated sludge was 96.4%.

Abuzaid et al (2002) studied the treatment of groundwater using electrocoagulation method. The experiments were carried out in an electrocoagulation reactor using soluble stainless steel electrodes. The influence of various parameters such as applied current, contact time, pH and conductivity of the wastewater sample were also studied for removal of turbidity. From the results it was found that the removal of turbidity was 95% at 1A current density and 5 min contact time.

Bejankiwar (2002) studied the treatment of cigarette industry wastewater by electrochemical process followed by chemical coagulation using Ca(OH)$_2$ as coagulant. From the results it was found that the removal of 56% COD and 84% BOD was achieved by electrochemical process at 3.5A current density and 5 h electrolysis using cast iron electrodes. Also found that the removal of 71.01% COD, 89.62% BOD and 80.59% TSS was achieved by electrochemical process followed by chemical coagulation.

Gursesa et al (2002) studied the decolorization of strong colored solutions containing the reactive textile dyes by electrocoagulation. The experiments were statistically designed and carried out according to a 24 full factorial design with two replicate and four center points. This design was extended with eight additional axial points. Then, the non-linear regression was applied on the data by using MINITAB software. The variables chosen for this work are mixing rate, cell voltage, electrolysis time and current density. Results showed that the effective variables on decolorization process are cell voltage, electrolysis time and current density. In addition, to determine the effect of dye and electrode type on decolorization, the additional experiments were carried out. It was determined the dye and electrode type are important on the decolorization process.
Daneshvar et al (2003) studied the decolorization of orange II by the direct current electrocoagulation (EC). The effect of initial pH, rate of stirring, concentration of dye, electrode distance, current density, water temperature etc were studied. The optimum operating range for each of these operating variables was experimentally determined. The experimental results revealed that the colour of orange II in aqueous phase was efficiently removed (98%) and also the chemical oxygen demand (COD) reduced (84%), when iron was used as sacrificial anode and the concentration of orange II was 200 ppm. The optimum current density was 34.62A/m² for effectively removing of orange II. The electrocoagulation method is found to be quite effective in removing of orange II.

Feng et al (2003) removed Fluoride ions electrochemically from industrial wastewater using a combined electrocoagulation and electroflotation process. In this study they used aluminum electrodes for both anode and cathode. The initial fluoride concentration was 15 mg/l, the effluent fluoride concentration can be lower than 2 mg/l when the pH in the coagulation cell is around 6, charge loading is at 4.97 F/m³ water, and the residence time is 20 min.

Kobya et al (2003) studied the treatment of textile wastewater by electrocoagulation using stainless steel as electrodes. The influence of various parameters such as wastewater conductivity, pH, current density and operating time were also studied for removal of turbidity. From the results it was found that the removal of turbidity was 95 % at a current density of 10mA/cm² and electrolysis time of 10 minutes.

Ge et al (2004) made a detail study for the treatment of laundry wastewater using bipolar electrocoagulation and electroflotation process. In this study, the electrocoagulation and electroflotation process were carried out in single reactor. The influence of operating parameters such as initial pH,
hydraulic residence time and current density were also studied. From the results it was found that the removal of turbidity, COD and phosphate was successfully achieved in the pH range of 5-9. The removal of COD was found to be greater than 70% and the removal of turbidity and P-phosphate was found to be 90%.

Lai and Lin (2004) studied the treatment of copper chemical mechanical polishing wastewater from a semiconductor plant by electrocoagulation. The experiments were carried out using Al/Fe pair electrodes. From the results it was found that the percentage of copper ion, turbidity and COD removal was 99, 96.5 and 85 respectively.

Nihal et al (2004) investigated the feasibility of boron removal from wastewater containing high boron concentration by using electrocoagulation. They used aluminum electrodes in the experiments. The process was examined under various factors in order to assess optimal operating conditions. They showed that boron removal by electrocoagulation process depends on current density, initial concentration and time. Removal of 92-96% has achieved under a current density of 30mA/cm².

Asselin et al (2008) studied the treatment of oil bilge wastewater (OBW) by electrocoagulation using iron and aluminum as working electrodes. From the results it was found that under the optimal conditions, the removal of biochemical oxygen demand, oil and grease, total suspended solids and turbidity were 93%, 95.6%, 99.8% and 98.4% respectively. Also found that under the optimal operating conditions, the total operating cost was $0.46/m³ for energy, electrode consumption, chemicals and sludge disposal.

Asselin et al (2008) studied the treatment of slaughterhouse wastewater by electrocoagulation using mild steel/aluminum as working electrodes. From the results it was found that the removal of total suspended
solids, turbidity, BOD and oil and grease were 89%, 90%, 86%, and 99% respectively. Also found that under the optimal operating conditions, the total operating cost was 0.71 USD$/m$ for energy, electrode consumption, chemicals and sludge disposal.

Hansen et al (2008) studied the removal of arsenic from wastewater by airlift electrocoagulator using iron as working electrodes. From the results it was found that the oxidation of Fe$^{2+}$ to Fe$^{3+}$ determines the arsenic removal efficiency. The removal of arsenic was found to be 96% for arsenic concentration greater than 500 mg/l whereas 98% arsenic removal was obtained for arsenic concentration of 100 mg/l. Also the rate of removal was found to be 0.08–0.1 mg As/C, where Fe-to-As ratio (mol/mol) was about 486.

Illhan et al (2008) studied the treatment of domestic wastewater by electrocoagulation using iron as working electrodes. From the results it was found that under the optimal conditions (0.6W electrical power, electrolysis time of 15 minutes for heavy load (380 mg COD/l) and 8 minutes for weakly loaded (260 mg COD/l)), the removal of COD and suspended solids were 60 and 70%, respectively. Also found that the electrical energy consumption were 0.4 and 0.2 kWh/m$ for heavy and weakly loads.

Ugur et al (2008) has tested the potential to treat domestic wastewater (DWW) using an electrocoagulation process on two different samples, one of which was heavily loaded (380 mg chemical oxygen demand COD/l); the other was weakly loaded (260 mg COD/L). The experimental studies were conducted within an electrolysis cell with Fe-Fe electrodes. The optimum operational conditions found for electrical power was 0.6 W for both DWW samples, and electrolysis times were found as 15 min for heavily loaded DWW and 8 min for weakly loaded DWW. The removal efficiency of COD and SS were obtained and shown to be over 60% and 70% respectively.
Yilmaz et al (2008) studied the removal of boron from synthetic wastewater by electrocoagulation. The experiments were carried out by varying the parameters such as pH, boron concentration, stirring speed and temperature. From the results it was found that the removal of boron was 99%. Also found that the boron removal and floc formulation decreased with increasing stirring speed and the boron removal increased with increasing temperature. The authors also developed a pseudo-second order model equation based on the heterogeneous fluid-solid reaction.

Maghana et al (2009) studied the treatment of tea effluent using electrocoagulation method. From the results it was found that under the optimal operating conditions (electrical potential of 24 V, interelectrode distance of 5 mm, effluent volume ratio of 18.2m²/m³, and a pH of 6), the removal of BOD and COD were 84% and 96.6% respectively.

Mikko Vepsalainen et al (2009) studied the effect of temperature and initial sample pH on natural organic matter removal with electrocoagulation using response surface method. In this study they used aluminum electrodes for both anode and cathode. From the results it was found that the removal of 80.4% dissolved organic carbon was achieved by electrocoagulation process at high electric charge per liter (144 C/l), low pH (4.3) and high temperature (295.15 K). Also found that the effect of temperature on natural organic matter removal was minor as compared to the effects of electric charge per volume and the initial pH. Also an empirical model was developed from the results by analysis of variance (ANOVA). Based on the results they suggest that the electrocoagulation treatment could be used for natural organic matter removal during cold water period in Nordic countries.

Tezcan Un et al (2009) studied the treatment of vegetable oil refinery wastewater by electrocoagulation using aluminum as working
electrodes. From the results it was found that the removal of COD was 98.9% at current density of 35 mA/cm$^2$ and electrolysis time of 90 min. Also found that under the optimal condition the energy consumption was 42 kWh/kg COD removed.

Wang and Chou (2009) made a detail study for treatment of oxide chemical mechanical polishing wastewater by electrocoagulation using iron as working electrodes. From the results it was found that the removal of chemical oxygen demand was 90% at NaCl concentration of 200 mg/l, electrical potential of 20 V and temperature of 25 degrees Celsius. With a 90% removal, it was noted that the water could be capable of being for possible reuse. The author also developed a pseudo-first order kinetic model.

Zhang et al (2009) studied the treatment of methyl orange simulate dye wastewater by electrocoagulation. From the results it was found that the removal of colour was 97% at electrolysis time of 10 minutes, electrical potential of 20 V, current density of 0.4 A, electrode distance of 2.5 cm, initial dye concentration of 500 mg/L, KCl concentration of 0.5 g/L and pH of 3. The authors also developed a model in which coagulation was determined for COD removal followed by oxidation.

Aoudj et al (2010) conducted a study to investigate the effectiveness of electrocoagulation for color removal of solution containing Direct red 81. Their experiments were performed for synthetic solution in batch mode. More than 98% of color removal was obtained at initial pH of 6, current density of 18750 A/m², and inter-electrode distance of 1.5 cm.

Ilona et al (2010) studied the performance of an electrocoagulation system for Ni, Cu and Cr removal from a galvanic wastewater. Several parameters and their influence on the removal results and on electrocoagulation efficiency were investigated. In this study they indicated
that electrocoagulation could be a good alternative to the conventional methods, by treating heavy removal contaminated wastewater in a concentration range up to a few hundred mg/l. The combination of Al-and Fe-electrodes and an initial pH value > 5 led to the removed results.

Malakootian et al (2010) evaluate the use of electrocoagulation process for removing hardness from drinking water. Iron-rod electrodes were used for this purpose. Their results indicated that using iron-rod electrodes in electrocoagulation process can be effective in removing water hardness. The greater removal effectiveness has occurred in pH of 10, voltage of 12 and 60 min time; which was 98.2%.

Merzouk et al (2010) studied the treatment of textile wastewater by combination of electrocoagulation-electroflotation. From the results it was found that under the optimal operating conditions (current density of 11.55 mA/cm², pH of 7.6, conductivity of 2.1 mS/cm, treatment time of 10 minutes and electrode gap of 1 cm) the removal of suspended solids, turbidity, biochemical oxygen demand, chemical oxygen demand and colour were 85.5%, 76.2%, 88.9%, 79.7% and 93% respectively.

Kobya et al (2010) studied the treatment of rinse water from zinc phosphate coating by both batch and continuous electrocoagulation process. In that study the effect of Al and Fe electrodes were investigated. From the results it was found that the phosphate and zinc removals were achieved by Al electrode at pH 5 and by Fe electrode at pH 3. Also found that the removal of phosphate and zinc were 97.7% and 97.8% for Fe electrode and 99.8% and 96.7% for Al electrodes respectively.

Serge et al (2010) studied the treatment of dairy effluents by electrocoagulation process. The experiments were carried out using a soluble aluminum anode and the flocks generated during electrocoagulation were
separated by filtration. From the results it was found that the percentage of chemical oxygen demand, phosphorus, nitrogen contents and turbidity removal were 61, 89, 81 and 100. Based on the analysis the authors suggested that the electrocoagulation technique could be used for treatment of dairy effluent.

Subramanyan et al (2010) conducted a study that presents an electrocoagulation process for the removal of chromium from water using magnesium as the anode and galvanized iron as the cathode. Several parameters effecting on the electrocoagulation process were investigated. The results showed that an optimum removal efficiency of 98.6% was achieved at a current density of 20 A/m² and a pH of 7.0.

Ashraf Shafaei et al (2011) studied the removal of Co (II) from aqueous solution by electrocoagulation process using aluminum as working electrodes. The effect of pH, current density, time, conductivity and initial metal concentration on the performance of electrocoagulation process were investigated. From the results it was found that the initial pH, current density and electrolysis period has a positive effect on the Co²⁺ removal efficiency. Also found that the electrical energy consumption decreased with increasing solution conductivity.

Feryal Akbal and Selva Cama (2011) investigated the removal of copper (Cu), chromium (Cr) and nickel (Ni) from metal plating wastewater by electrocoagulation with iron and aluminum electrodes with monopolar configurations. In that study the influence of electrode material, current density, wastewater pH and conductivity on removal performance was explored. From the results it was found that the metal removal increased with increasing current density, pH and conductivity. Also found that electrocoagulation with a Fe–Al electrode pair was very efficient and was able to achieve 100% Cu, 100% Cr and 100% Ni removal at an electrocoagulation
time of 20 min, at a current density of 10mA/cm² and a pH of 3. Under the optimal operating conditions the energy and electrode consumptions were 10.07 kWh/m³ and 1.08 kg/m³ respectively.

Serkan Bayar et al (2011) studied the effect of current density and stirring speed on the treatment of poultry slaughterhouse wastewater using electrocoagulation with aluminum electrodes. The experiments were carried out by varying the initial pH and current density between 3 and 7, and 0.5 and 2.0 mA/cm² respectively. From the results it was found that the COD removal efficiency decreased with increasing current density. The highest removal efficiencies of 85, 85, 81 and 71% were obtained with the current density of 0.5, 1.0, 1.5 and 2.0mA/cm², respectively and turbidity removal efficiency of 98% was achieved at current density of 1.0 mA/cm². Also found that removal efficiency of 85, 90 and 75% were achieved at 100, 150 and 250 rpm of stirring speed with the current density of 1.0 mA/cm².

Shanthi et al (2011) studied the treatment of domestic sewage using electrochemical technique. The experiments were carried out at different current densities and different volume in a batch electrochemical reactor using Ti/RuO₂ as anode and stainless steel as cathode. From the results it was found that the percentage of chemical oxygen demand and colour removal were 97.8 and 100.

Erhan Gengec et al (2012) studied the treatment of baker's yeast wastewater by electrocoagulation using aluminium as working electrodes. The experiments were carried out in a batch electrolytic reactor made off Plexiglas material. From the results it was found that the removal of colour, COD and TOC were 88%, 48% and 49% at current density of 80A/m², pH₀ of 4 and electrolysis time of 30 min for anaerobic effluent and 86%, 49% and 43% at current density of 12.5A/m², pH₀ of 5 and electrolysis time of 30 min for anaerobic–aerobic effluents, respectively. The operating costs for
anaerobic and anaerobic–aerobic effluents at the optimized conditions were 0.418€/m$^3$ and 0.076€/m$^3$. Also found that the quadratic model fitted very well with the experimental data. R$^2$ correlation coefficients (>95%) for the removal efficiencies showed a high significance of the model.

Bassam Al Aji et al (2012) investigated the performance of batch electrocoagulation (EC) using iron electrodes with monopolar configuration for simultaneous removal of copper (Cu), nickel (Ni), zinc (Zn) and manganese (Mn) from a simulated wastewater. The experiments were carried out in a batch stirred cell to determine the influences of current density (from 2 to 25mA/cm$^2$), initial metal concentration (from 50 to 250 mg/L) and initial pH (3, 5.68 and 8.95) on removal efficiency. From the results it was found that under the optimal conditions the electrocoagulation removes heavy metals from the simulated wastewater efficiently having an initial concentration of 250 mg/l for each metal. Also found that more than 96% removal efficiency was achieved for all metals except Mn, for which the removal efficiency was only 72.6%. Total energy consumption was found to be 49 kWh/m$^3$ at current density of 25 mA/cm$^2$.

Mikko Vepsalainen et al (2012) studied the effect of electrochemical cell structure on natural organic matter removal from surface water through electrocoagulation. The experiments were carried out by one that only had aluminum electrodes, one that had aluminum anodes and inert cathodes, and one that had inert anodes and aluminum cathodes. From the results it was found that the electrocoagulation was able to produce high quality water with low natural organic matter concentration and the lowest measured TOC concentration was 4.02 mg/l (78% removal). Also found that Aluminum originating from the anodes or cathodes had similar natural organic matter removal efficiency. Also a statistical model was developed from the results using partial least squares regression.
Subramanyan Vasudevan et al (2012) investigated the removal of mercury, lead and nickel from contaminated water by electrocoagulation process. The experiments were carried in an electrolytic cell consisted of a 1.0-L Plexiglas vessel. Magnesium alloy, magnesium, aluminum and mild steel of surface area 0.02 m\(^2\) acted as the anode. The cathodes were galvanized iron sheets of the same size as the anode. The results showed that the maximum removal efficiency was achieved at a current density of 0.15 A/dm\(^2\) and pH of 7.0 for mercury, lead, and nickel using magnesium alloy as anode and galvanized iron as cathode. The result showed that the adsorption is depends on both magnesium hydroxide and mercury, lead and nickel concentrations.

2.5 CONCLUSIONS FROM THE LITERATURE REVIEW

Mahesh et al (2006) studied the electrochemical degradation of pulp and paper mill wastewater and found that the overall removal of COD and colour were 91% and 100%, respectively. Ben Mansour et al (2007) studied the treatment of paper industrial effluent by batch and continuous mode of electrofloatation and found that the removal efficiency of suspended solids in both the cases was more than 95%. Parama Kalyani et al (2009) studied the treatment of black liquor from paper industry by electrocoagulation and found that the maximum colour and COD removal efficiencies were 92%, 95% and 84%, 89% for mild steel and aluminum electrode respectively. Zaied et al (2009) studied the treatment of black liquor from paper industry by electrocoagulation and found that the removal of COD, polyphenols and colour were 98%, 92% and 99% respectively. Ugurlu et al (2007) reported more than 70% COD and lignin removal from pulp and paper effluent through electrocoagulation. Wang et al (2007) studied the electrochemical treatment of paper mill wastewater using three dimensional electrodes with Ti/Co/SnO\(_2\)-Sb\(_2\)O\(_3\) anode and reported the maximum colour and COD removal was 75%.
Patel et al (2008) studied the removal of Adsorbable Organic Halides (AOX) compounds produced during bleaching of pulp by electrochemical treatment and found that the removal of initial colour, COD and AOX were more than 90%. Sittichok Khansorthong et al (2009) studied the treatment of pulp and paper industry effluent by electrocoagulation technique and found that the removal of colour and COD were 91% and 77% for iron plate electrode. Soloman et al (2009) studied the treatment of pulp and paper industry effluent by electrochemical treatment and the removal of COD and colour were found to be 55% and 87%.

Harris and Moats (1975) studied a laboratory method involving pH adjustment and heating to recover egg solids from egg processing wastewater. The results indicated that the removal of biochemical oxygen demand and chemical oxygen demand were 90% and 97% respectively. Also found that the recovered solids contained a high concentration of protein, which make them a potentially valuable by-product for use in livestock feeds. Bough (1975) studied the treatment of wastewater generated from egg breaking section using 100 to 200 mg/l Chitosan and 2 to 20 mg/l Betz polymers. The results showed that the total solids and chemical oxygen demand were reduced by 70 to 90% and 55 to 75%, respectively depending on the process conditions. Bulley (1976) studied the recovery of by-products from egg processing wastewater using 200 mg/l aluminum sulfate. The results showed that the coagulation treatment techniques removed 38 to 92% and 80 to 89% of the total solids and BOD, respectively depending on the quantity of coagulant added. Also found that the recovered solids were not acceptable for use in livestock feed because of the presence of alum. Xu (2001) studied the treatment of egg processing wastewater using different coagulants such as lignosulfonate, bentonite, carboxymethylcellulose, and ferric chloride and found that the removal of chemical oxygen demand, turbidity and total solids were 90%, 97% and 95%, respectively, for all coagulants.
Rajesh et al (1999) studied the treatment of rice mill wastewater using two stage upflow anaerobic sludge blanket (UASB) bioreactor and found that the removal of BOD and COD were 89% and 78% respectively at loading rate of 3 kg COD m$^3$ d$^{-1}$ and HRT of 30 hrs. Manogari et al (2008) investigated the treatment of rice mill wastewater using pseudomonas sp. and found that the removal of COD and BOD were 86.44% and 55.34% respectively after 24 hours using immobilized packed bed system. Manaswini Behera et al (2010) studied the performance of microbial fuel cells (MFC) made of earthen pot and a proton exchange membrane for treatment of rice mill wastewater and the removal of COD was found to be 96.5% and 92.6% for earthen pot MFC and proton exchange membrane MFC respectively at feed pH of 8.

From the review of literature, the following are the major conclusions.

- Conventionally, the industrial effluents are treated by many different techniques such as adsorption, membrane filtration, coagulation–flocculation, advanced oxidation processes such as ozone, photochemical and Fenton's method etc.

- The conventional technologies take considerable time and require an extensive setup for treatment of effluent. Moreover, each step takes place in a separate tank and the entire treatment requires several pH adjustments as well as the addition of chemicals. The conventional processes generate a considerable quantity of secondary pollutants and large volumes of sludge which it needs further treatment.

- The biological treatment processes are more suitable for treatment of high strength organic effluent and the high
organic effluent requires a two-stage (anaerobic + aerobic) treatment system to degrade the organic components efficiently. Apart from this, the biological treatment technology is still not optimal as the total treatment efficiency in terms of COD is only about 80%.

- Few authors used biological process combined with other processes such as physico-chemical methods. The drawbacks for addition of conventional with biological techniques, leads generation of secondary pollution and increases the cost of operation.

- The electrocoagulation method appear to be effective for the treatment of different industrial effluents such as olive mill, distillery industry, dairy industry, pulp and paper industry, textile industry, poultry slaughterhouse, yeast industry etc., compared with conventional methods.

- Electrocoagulation process provides a simple, reliable and cost effective method for the treatment with short reaction time and low sludge production. This technique needs no additional chemicals and therefore does not produce secondary pollution.

- Most of the authors used successfully electrocoagulation method for treatment of black liquor from paper and pulp industries. Very limited authors have been reported for treatment of bleaching effluent from paper and pulp industries using electrocoagulation method.

- Very few authors used coagulation and biological method for treatment of egg processing effluent and rice mill effluent
(Manogari et al 2008, Bough 1975, Manaswini Behera et al 2010). Egg processing effluent and rice mill effluent using biological method is found to be low, whereas the treatment efficiency of the effluent using chemical coagulation processes is good but it generates a considerable quantity of sludge which needs further treatment.

Hence, in this present research an attempt has been made to study the efficiency of electrocoagulation process for treatment of bleaching, egg processing and rice mill effluent as a function of operating parameters such as electrolysis time, current density, initial pH, electrolyte concentration, rotational speed and electrode distance on colour, turbidity, COD and BOD reduction. The problem definition, its objectives and salient future of the present work are presented in the next chapter 3.