CHAPTER 2

REVIEW OF LITERATURE

In ancient times, tanning was considered a noxious and foul smelling procedure carried out in the outskirts of towns where the old methods were practiced. Leather industry is one of the oldest cottage industries in India. Until the late 1800s, animal skin was air or salt dried and tanned with vegetable tannins or oil, but today animal skin is turned into finished leather with a variety of much more dangerous substances including - mineral salts, formaldehyde, coal tar derivatives and various oils, dyes and finishes, some of them are cyanide-based. More than 500 tanneries in three districts in India were charged with polluting some 16,000 hectares of agricultural land and contributing to drought conditions (The Hindu 2004).

Tanneries are typically characterized as pollution intensive industrial complexes which generates widely varying, high strength waste water. Tannery effluent is among one of the hazardous pollutants of industry. Although tanning has been in existence for a long time, the problem of environmental pollution received serious consideration only in recent years. The discharge of Cr (VI) into aquatic ecosystems has become a matter of concern in all the tannery areas in India over the last few decades (Singh et al. 2009).

In India some sites are identified as the most polluted sites namely Sukinda valley in Orissa, Vapi in Gujarat, Mahad in Maharashtra, Noraiakheda, Kanpur, in Uttar Pradesh and Ranipet in Tamilnadu as these places have chrome mining, tanneries, textile and other industries and discharge effluent containing higher concentration as per data released by Blacksmith Institute, Newyork, USA (2007). In fact, according to a report
issued by the Institute, the health of 3.5 million people in Ranipet, Tamil Nadu, India, has been endangered by a factory that produces the salts used in nearby tanneries. Further the Institute included the area in its annual “Dirty Thirty” list of the world’s most contaminated sites. In 2012 the Institute announced “tanneries” in the fourth place among the top 10 list of the world’s “Toxic Pollution Problems” (Blacksmith Institute 2012).

2.1 Harmful Effects of Tannery Effluent

Heavy metals exhibit toxic effects on soil biota and they can affect key microbial processes and decrease the number and activity of soil microorganisms (Obbard 2001). Aina et al. (2007) observed that the fertility of the soil is affected when tannery wastes gain access to cultivable lands or when the lands are irrigated with such wastes. Heavy metals in the tannery effluent are one of the most hazardous environmental pollutants, which are bioaccumulated in plants and adversely affect the plant growth and metabolism. These wastes reduce germination, growth and yield of grains and lettuce crops (Castilloss et al. 2007 and Babyskakila 2009).

According to Tudunwada et al. (2007) over 62% of ordinary people and 72% of tannery workers have contracted one or more problems like cancer, respiratory infections, tuberculosis, loss of eyesight, liver and abdominal diseases, kidney and urinary infections etc. Shivakumar and Thippeswamy (2012) are of the opinion that chromium and nickel are the causative agents for bronchitis and cancer, the major diseases of cattle and human beings. Singh et al. (2011) considered tannery waste as one of the most polluted industrial wastes which contains high amounts of metals which are very toxic to plants, animals and soil.
Pollutants are introduced into the aquatic systems of leather processing units as a result of chrome tanning of leather. Interactions of chromium with biological systems are very different and complex (Upreti et al. 2004). Based on review of available literature, about 10% of ingested Cr (VI) is absorbed in the gastrointestinal tract (Lodato et al. 2007).

Wastewater from dyeing units is often rich in colour, containing residues of reactive dyes and chemicals and requires proper treatment before being released into the environment. The discharge of waste water containing recalcitrant residues into rivers and lakes lead to higher biological oxygen demand (BOD) causing serious threat to native aquatic life (McMullan et al. 2001).

2.2 Microbes in Bioremediation

Microbes in the environment play an important role in the cycling of organic chemicals and can destroy them through biodegradation. Microbial population has amazing enzymatic and metabolic potential to degrade a variety of organic compounds. Microorganisms regenerate quite rapidly in the environment and over a period of time developed the genetic competence to synthesize enzymes and other cell components that are necessary for the dissimilation of environmental chemicals. The complete biodegradation of organic chemicals in the natural ecosystem is primarily due to microorganisms. Hence, biotechnological applications employ microbes or their enzymes for waste treatment. Bacteria and fungi are the chief agents for the biodegradation of organic compounds. Yeast, algae and diatoms as well as some higher plants and animals also metabolize variety of chemicals (Ninnekar 1992).

Devi (2011) suggested that instead of using physical and chemical treatment techniques, biotechnological application using microbes or their
enzymes for waste treatment are more efficient. The physico-chemical characteristics of tannery effluent from a tannery at Sembattu in Tiruchirappalli District, Tamil Nadu, were analyzed by Aneez Mohamed et al. (2011). They also experimented to reduce the load of BOD and COD by the process of bioremediation using microorganisms. Bacterium, *Bacillus cereus* and fungus, *Aspergillus niger* were isolated, identified and used in the reduction of BOD and COD in the tannery effluent collected from Erode, Tamilnadu (Subramani and Haribalaji 2012).

Microorganisms are used for removal of toxic heavy metals from industrial effluents. Bioaccumulation of chromium by algae, *Chlorella vulgaris, Anabena doliolum* and fungal biomass has been reported (Mallick and Rai 1994 and Kapoor and Viraraghavan 1995).

Zouboulis *et al.* (1999) studied the biosorption of toxic metals from aqueous mixture containing zinc, copper and nickel in the presence of calcium and sodium ions. They also observed industrial biomass samples of different origin as effective sorbents including bacteria (*Streptomyces rimosus*), fungi (*Penicillium chrysogenum*) and yeast (*Saccharomyces carlbergensis* and *Saccharomyces cervisiae*).

Kapoor *et al.* (1999) and Magyarosy *et al.* (2002) found that the high surface to volume ratio of microorganisms and their ability to detoxify metals are the main reasons for their use as potential alternative to synthetic resins for remediation of dilute solutions of metals and solid wastes.

Microorganisms can play an important role in the detoxification or removal of heavy metals from polluted environments (Badar *et al.* 2000). There are certain microorganisms which can survive in high oxygen demand and high concentrations of metals with high potential to accumulate different metals.
This is achieved by virtue of covalent interaction of metal at cell surface or within the cell by different processes (Bhanooori and Venkateswerlu 2000).

Use of microorganisms for removal of toxic heavy metals from effluents and colour from dye are reported (Viraraghavan and Yan 2003; Canizares-Villanueva et al. 2004 and Ma et al. 2004). Industrial waste water contains chromium and ions of various salts which have toxic effects on the microbial consortia of waste water treatment systems (Stasinakis et al. 2003). Removal of Cr (VI) either by reduction or by biosorption can significantly reduce the risks to human health (Kamaludeen et al. 2003). The first report on Cr (VI) removal by a microbial culture in a pneumatically agitated bioreactor is that of Morales-Barrera and Cristiani-Urbina (2006).

Microorganisms have developed the capabilities to protect themselves from heavy metal toxicity by various mechanisms, such as adsorption, uptake, methylation, oxidation and reduction. Reduction of metals can occur through dissimilatory metal reduction (Fernandez et al. 2012).

The dyes themselves are generally resistant to oxidative biodegradation. It has been demonstrated that mixed bacterial cultures are capable of decolourizing textile dye solutions not by biodegradation but by adsorption to the microbial biomass (Slokar and Majcen 1998).

Physicochemical treatment methods for the removal of dyes are not economically feasible as they produce large volumes of sludge. Lately, microbial degradation of azo dyes has been attracted significant attention. Microbial degradation of azo dyes has been reported using yeast (Martins et al. 1999), bacteria (Rajaguru et al. 2000), different microorganisms (McMullan et al. 2001) and filamentous fungi, such as the white rot fungi (Martins et al. 2001 and Pointing 2001). Several triphenylmethane dye-degrading microorganisms have been reported (Naggar et al. 2004 and Chiing-Chang et al. 2007).
However, it is reported that efficiency of microorganisms in decolorisation of dyes depends on the adaptability and the activity of selected microorganisms (Kodam et al. 2005; Aksu et al. 2007 and Dave and Dave 2009).

The biodegradative pathways have also been reported in bacteria from the genera *Mycobacterium, Corynebacterium, Aeromonas, Rhodococcus* and *Bacillus* (Mrozik et al. 2003).

The nitrate reducing bacterial strains *Pseudomonas* sp. and *Brevibacillus* sp. were isolated from petroleum contaminated soil (Grishchenkov et al. 2000). Many bacteria are able to metabolize organic pollutants. However, a single bacterium does not possess the enzymatic capability to degrade all the organic compounds in a polluted soil. Mixed microbial communities have been found the most powerful biodegradative potential because the genetic information of more than one organism is necessary to degrade the complex mixture of organic compounds present in contaminated areas (Fritsche and Hofrichter 2005).

Several bacteria are known to feed exclusively on hydrocarbons (Yakimov et al. 2007). Nayaresh (2009) biodegraded phenol using a bacterial strain isolated from a phenol contaminated site. Yang and Lee (2009) employed bacterial strains such as *Pseudomonas resinovovus* and *Brevibacillus* sp., for the removal of phenol from waste water. They found that these organisms degraded phenol completely within 57.5 hours and 93.1 hours respectively. Kafilzadeh et al. (2011) isolated 80 bacterial strains which belonged to 10 genera. They found that *Bacillus* was the best hydrocarbon degrading bacterial strain. Other strains identified by the authors included *Corynebacterium, Staphylococcus, Streptococcus, Shigella, Alcaligenes, Acinetobacter, Escherichia, Klebsiella* and *Enterobacter*. Ebtesam El-Bestawy et al. (2013) isolated and identified 17 bacterial strains from the tannery effluents of Saudi
Arabia. They used 3 indigenous and 3 exogenous bacterial isolates in a batch mode remediation process as individual or mixed free living cultures for bioremediation of tannery effluents and observed that *Pseudomonas stutzeri* was the most efficient and *Bacillus* sp. was the least efficient bacteria in removing all the tested physico-chemical parameters.

Heavy metals cannot be destroyed biologically but are only transformed from one state to another or can be converted to a stable form or removed. Bacteria are efficient in heavy metals bioremediation (Garbisu and Alkorta 2001 and Lloyd and Lovley 2001). The various methods employed by bacteria are as follows:

- **Precipitation** - Metals can be precipitated as insoluble sulfides indirectly by the metabolic activity of sulphate reducing bacteria (White *et al.* 1998).
- **Entrapping** - *Pseudomonas* strain is a potent accumulator of uranium (VI) and thorium (IV) (Pinakisar *et al.* 2004).
- **Oxidation** - Acidophilic iron bacteria like *Acidithiobacillus ferrooxidans* and sulfur oxidizing bacteria are able to leach high concentrations of As, Cd, Cu, Co and Zn from contaminated soils (Takeuchi and Sugio 2006).
- **Methylation** - Hg (II) can be biomethylated by a number of bacterial species *Alcaligenes faecalis, Bacillus pumilus, Bacillus* sp., *Pseudomonas aeruginosa* and *Brevibacterium iodinium* to gaseous methyl mercury (De Jaysankar *et al.* 2008).
- **Reduction** - Cr (VI) is reduced to Cr (III) under aerobic or anaerobic conditions (Zhu *et al.* 2008).

Adarsh *et al.* (2007) have used an environmental bacterial consortium to remove Cd, Cr, Cu, Ni and Pb from a synthetic waste water effluent. For Cr (VI) removal, the survival and stability of bacteria were better when they were present as a mixed culture, especially in highly contaminated areas and in the presence of more than one type of metal.
Forty-one isolated actinomycetes were used to study qualitative and semi-quantitative screening of Cr (VI) resistance by Polti et al. (2007). Eleven Cr (VI) resistant strains were characterized and identified as species of the genera *Streptomyces* (10) and *Amycolatopsis* (1). The authors found that the composition of actinomycetes community in the contaminated and non-contaminated soil was different. Their study also showed the potential capacity of actinomycetes as tools for Cr (VI) bioremediation.

*Bacillus* sp., *Enterobacter cloacae*, *Escherichia* sp., *Pseudomonas* sp., *Oscillatoria* sp., *Arthrobacter* sp., *Agrobacterium radiobacter*, sulphate-reducing bacteria and also some yeasts and fungi were reported capable of reducing Cr (VI) to Cr (III). Thus these organisms were found to be promising agents in bioremediation of chromium through bio-absorption and bioaccumulation (Vermaa et al. 2001; Srinath et al. 2002; Morales et al. 2007; Pandi et al. 2009 and Polisak et al. 2009).

It is reported that the indigenous bacteria enriched from chromium contaminated biotopes were able to remove Cr (VI) successfully in multi-contaminated heavy metal solution (Joutey et al. 2011 & 2014).

Extensive reports are there on bacterial strains that are able to degrade azo dyes under aerobic and anaerobic conditions (Dos et al. 2007). Chaube et al. (2010) have used the mixture of bacteria consisting of *Proteus* sp., *Pseudomonas* sp. and *Enterococcus* sp. in biodegradation and decolourisation of dye. Microbial consortium consisting of three species of *Pseudomonas* originally obtained from dye contaminated sites was capable of decolourizing textile effluent and dye faster than the individual bacteria under static conditions (Jadhav et al. 2010). However, several researchers have identified single bacterial strains that have very high efficacy for removal of azo dyes.
Hong et al. (2007) used *Shewanella*, a single bacterial strain for removal of azo dyes.

Pure culture of bacterial strains can be used for the azo dye decoloration which is more advantageous than the use of mixed culture. In the pure culture technique performance of the candidate species can be evaluated under given set of environmental conditions. The activity of the bacterial strains can be monitored using culture-based or molecular methods to quantify population densities of the bacteria over time. This can be used for quantitative analysis of azo dye decolouration and mineralization (Khalid et al. 2010).

It has also been reported that few species of algae are capable of degrading azo dyes and utilize them as a sole source of carbon. Some articles on yeast capable of dye decolourization can also be found in the literature (Joshi et al. 2004).

Biological decolourization of dye effluent is receiving much consideration due to cost effective and less regeneration by microorganisms such as bacteria, fungi, actinobacteria, yeast, algae and plants. Recent promising research on biological decolourization of textile effluent has showed that variety of microorganisms and plants are capable of decolourizing wide range of anionic and cationic dyes (Ramachandran et al. 2013).

**2.3 Role of Fungi in Bioremediation**

Although basidiomycetes assume a noticeable importance in possible industrial applications, other fungi such as deuteromycetes have also been studied by Schoeman and Dickinson (1997). They found that *Aureobasidium pullulans*, a deuteromycete has the ability to degrade industrial aromatic compounds such as the lignin breakdown products.
Hafez et al. (1997), Tsezos et al. (1997) and Gardea-Torresdey et al. (1998) pointed out that fungal cell walls and their components have major role in the biosorption of heavy metals. Fungal biomass can take up considerable quantities of heavy metals from aqueous solution by adsorption or a related process, even in the absence of physiological activity (Gadd and White 1989). Many fungal species such as *Rhizopus arrhizus*, *Penicillium spinulum*, *Phanerochaete chrysosporium* and *Aspergillus niger* have been extensively studied for heavy metal biosorption and the process of adsorption was found to be species dependent (Mowll and Gadd 1983; Zhou and Kiff 1991; Krantz-Rülcker et al. 1996 and Saglam et al. 1999). Biosorption considerably depends on the experimental conditions such as pH value and metal concentration (Say et al. 2001).

Anand et al. (2006) while studying about bioaccumulation of copper by *Trichoderma viridae* observed that fungi can adapt and grow under various extreme conditions of pH, temperature and nutrient availability as well as high metal concentrations.

Fungi are often found functioning together with bacteria and as an array of microorganisms. It is the fungi that can especially handle breaking down some of the largest molecules present in nature (Fernandez-Luqueno et al. 2010). Maria et al. (2011) used the fungus *Botryosphaeria rhodina* for biotreatment of industrial tannery waste water and concluded that the concentration of organic compounds present in the tannery effluent was sufficient for microorganism growth, during which the COD and TOC were reduced by about 91 and 93 %, respectively.
2.4 Fungal Diversity in Tannery Effluent

The tannery effluent is rich in organic and inorganic nutrients which supports the growth of fungal population. Baldi et al. (1990) isolated chromium resistant yeast from sewage treatment plant receiving tannery effluent. Govindan and Uma (1991) identified 36 species of mycoflora from waste stabilization ponds containing sewage and have attributed the high TDS concentration in the sewage to favour the growth of the mycofloral population. Raman and Sambandan (1998) studied the distribution of VAM fungi in tannery effluent polluted soils of Tamil Nadu. From three sites of effluent polluted soils, 15 species of VAM fungal spores were isolated and identified.

Rao and Rao (2000) reported the occurrence of 10 species of fungi in the effluent, which are very significant in their utility as biological indicators. Six fungal species were identified in tannery effluent by Krishna Priya (2010). Seven different fungal species Aspergillus niger, A. flavus, A. fumigatus, Fusarium oxysporum, Penicillium chrysogenum, Mucor sp. and Trichoderma viride were isolated and identified by Saranraj et al. (2010).

2.5 Role of Fungi in Bioremediation of Chromium and other Heavy Metals

The commonly applied methods for the treatment of industrial effluents are by precipitation, ion exchange, electrochemical process, membrane processes and adsorption (Uang and Shiau 2000).

Kovacevic et al. (2000) used fungal pellets of Aspergillus niger from aqueous solution for biosorption of Cr, Cu, Ni and Zn ions. They found that intact microbial cell, live or dead and their products are highly efficient bioaccumulators.
Number of basidiomycetes is reported to have great promise for heavy metal ions removal from waste water. Their mycelium excretes enzymes that breakdown complex substances into simpler molecules and absorb heavy metals (Gadd 2000).

The ericoid fungus *Oidiodendron maius* was isolated from mycorrhizal roots of European blue berry *Vaccinium myrtillus* and was allowed to grow in heavy metal contaminated soil. When growth was compared with isolates from non polluted soils, a better performance was observed in the presence of increasing concentrations of zinc salts (Martino *et al.* 2000).

Brenda *et al.* (2001) compared the biosorptive capacity of dried biomass fungus *Rhizopus oryzae* for metal sorption with commercially available sources of chitin, chitosan and chitosan cross linked with benzoquinone. Yan and Viraraghavan (2001) documented heavy metal removal by immobilized *Mucor rouxii* in a biosorption column. The simultaneous biosorption of Cr (VI) and Fe (III) ions as a single component and the binary systems has been studied using *Rhizopus arrhizus*, a filamentous fungus, in a semi-batch reactor (Sag *et al.* 2004).

Bai and Abraham (2002) reported the biosorption of Cr (VI) by chemically modified biomass of *Rhizopus nigricans* and the possible mechanism of chromium complexation to the adsorbent. Removal of heavy metals by an *Aspergillus terreus* strain immobilized in a polyurethane matrix was carried out by Dias *et al.* (2002).

Only limited studies have been conducted to systematically screen filamentous fungi from metal polluted sites for their diversity, metal tolerance and their biosorption potential. Considering the various mechanisms of metal
resistance in fungi, it is expected that screening of metal tolerant fungi may provide strains with improved metal accumulation (Bai and Abraham 2003).

Barros et al. (2003) carried out a study on biosorption of cadmium using the fungus *Aspergillus niger*. They proved that heavy metal concentrations of 5 to 10 mg/l can be biosorbed with a biomass concentration of 0.7 gm/l of *Aspergillus niger* from oil field water in the oil industry.

The effect of Cu (II), Fe (II) and Cr (VI) ions on the growth and bioaccumulation properties of *Aspergillus niger* was investigated as a function of initial pH and initial metal ion concentration by Dursun et al. (2003).

Free and immobilized biomass of *Cunninghamamella echinulata* was used as a biosorbant of metal ions in waste water (El-sayed and El-Morsey 2004). The chitin and chitosan were extracted from mycelial biomass of *Cunninghamella elegans* and the performance for copper, lead and iron biosorption in aqueous solutions was evaluated by Franco et al. (2004).

Deng and Ting (2005) studied the biosorbant capacity of fungal biomass for Cr (VI). Prasenjit and Sumathi (2005) used *Aspergillus foetidus* which has the ability to take up chromium during the stationary phase of growth and under growth non supportive conditions.

Nouri et al. in 2005 studied and recognized the capability of algae, fungi and bacteria in the removal of heavy metals from industrial effluent. In this research, growth of *Aspergillus oryzae* in the tanning house effluent and its capability in bioremoval of chromium were assessed.

A modified fungal biomass of *Penicillium chrysogenum* with positive surface charge was prepared by grafting polyethylenimine (PEI) onto the
biomass surface in a two-step reaction. This biomass was used for removal of Cr (VI) (Shubo and Yen 2005).

Vala et al. (2005) while studying Cr (VI) tolerance by two fungal strains of Aspergillus flavus and Aspergillus niger associated with marine seaweed (Euchuma sp.) reported that both the isolates accumulated more than 25% of the Cr(VI) supplied. Among the two species A. flavus showed luxuriant growth and higher accumulation potential in different concentrations of 25, 50 and 100ppm Cr (VI).

Acevedo-Aguilar et al. (2006) studied the Cr (VI) removal in vitro and from industrial wastes, using chromate-resistant strains of filamentous fungi indigenous to contaminated wastes. Their results indicated that chromate-resistant filamentous fungi with Cr (VI) reducing capability could be useful for the removal of Cr (VI) contamination.

Ahmad et al. (2006) studied the biosorption of Ni, Cr and Cd by metal tolerant Aspergillus niger and Penicillium sp. using single and multi-metal solutions. Aspergillus niger and Penicillium sp. resistant to Ni, Cd and Cr were isolated from soil receiving long term application of municipal waste water mix with untreated industrial effluents of Aligarh, India. These two isolates were tested for their Cr, Ni and Cd biosorption potential using alkali treated dried and powdered mycelium.

The biosorption of eight different metals from aqueous solutions of combined industrial effluent by live or dead cells of Phanerochaete chrysosporium was investigated by Ravindra and Sripathi (2006). They concluded that the dead fungal biomass was more effective than the living fungus for biosorption of metals.
The potency of *Aspergillus niger* isolated from soil and effluent of leather tanning mills was evaluated in shake flask culture by Shaili (2006). Biosorption of chromium from aqueous solution by a tropical basidiomycete BDT-14 was reported by Trivedi and Patel (2006). Removal of Cr (VI) from aqueous solution was carried out in batch experiments using dead biomass of four fungal strains of *Aspergillus* (Srivastava *et al.* 2007).

Morales *et al.* (2007) used fungal strain *Trichoderma inhamatum* for removing Cr (VI) isolated from industrial effluent from a leather factory located in the city of Guadalajara, state of Jalisco, Mexico. Experimental results suggested that the fungus is capable of transforming Cr (VI) to Cr (III), a transformation of a highly toxic contaminant to a low toxic form. The fungus exhibited a remarkable capacity to tolerate and completely reduce Cr (VI) concentrations up to 2.43 mM. Recent reports have also examined Cr (III) and Cr (VI) uptake and accumulation by different filamentous fungi (Fukuda *et al.* 2008).

Venkata Subbaiah *et al.* (2008) studied the removal of Cr (VI) from aqueous solution using abundantly available *Trametes versicolor* fungi as a biosorbing medium under equilibrium and column flow conditions. Various sorption parameters such as contact time, effect of pH, concentration of Cr (VI) and amount of biomass on the adsorption capacity of the biosorbant were studied. The experimental results demonstrated that the *Trametes versicolor* fungi could be used as sorbent for immobilizing Cr (VI).

Ezzouhri *et al.* (2009) suggested that removal of heavy metals from waste water through biosorption using fungal biomass is a very good remedy as they have a high level of resistance to metals which make them attractive potential candidates for such purpose. Not only the living biomass but also the
dead one can be utilized in the biosorption processes with the latter being more effective in most cases (Pang et al. 2010 and Hemambika et al. 2011).

Sen and Dastidar (2010b) suggested that isolated fungus from soil used as biosorbant for the removal of Cr (VI) from aqueous solution has assumed advantageous over the existing conventional, physico-chemical techniques for the treatment of metal contaminated wastes. Murugan et al. (2011) isolated *Aspergillus niger* capable of producing tannase which was able to degrade tannin, a major constituent of tannery effluent.

Surumbar Kuzhali et al. (2012) experimented with basidiomycetes fungi *Pleurotus florida* and *Calocybe indica* for their heavy metal absorption from tannery effluent from Begambur, Dindigul, Tamilnadu and found that both species are potential biosorbants of heavy metals like Cr, Ni and Zn.

Three fungi namely *Aspergillus niger*, *Penicillium* sp. and *Fusarium* sp. were identified and selected for the bioremedial studies by Bhuvaneswari et al. (2013). All the three were known to bring about bioremediation which had been confirmed by measuring the percentage of reduction potential in pH, EC, TDS, OD, BOD, COD and increase in fungal growth.

### 2.6 Role of Fungi in Dye Degradation

Azo dyes, which are aromatic compounds with one or more (−N=N−) groups, are the most important and largest class of synthetic dyes used in commercial applications (Vandevivere et al. 1998).

These dyes are generally considered to be non-biodegradable under aerobic condition because of their structure. However, Cripps et al. (1990) suggested that the non specific nature of the lignin-degrading system of the
dyes could be expected to be effective in the degradation of these dyes. Treatment of waste water containing these dyes usually involves physical and chemical methods such as adsorption, coagulation-flocculation, oxidation, filtration and electrochemical methods (Verma and Madamwar 2003).

Azo dyes are released in large quantities into the environment from textile industries. These dyes are recalcitrant to microbial degradation, causing problems in the usual biological treatment of the industrial effluents (Swamy and Ramsay 1999).

Ligninolytic fungi are potentially capable of degrading lignin and other structurally complex pollutant present in solid industrial waste or waste water (Jong et al. 1992). The oxidative mechanisms of fungi prevent the formation of hazardous anilines due to reduction of azo dyes by other microorganisms such as bacteria (Chung and Stevens 1993).

White rot fungi produce several enzymes that have been related to their ability to degrade natural polymers, such as lignin and cellulose, but can also degrade different synthetic chemicals, usually recalcitrant to biodegradation (Field et al. 1993). One of the well-characterized white rot fungi for industrial use is the basidiomycete, *Phanerochaete chrysosporium*. The fungus is capable of producing some non-specific extracellular enzymes viz. the ligninolytic peroxidases that have been used in the degradation of dyes (Ollikka et al. 1993).

The promising results obtained with the ligninolytic fungus, lead to the study of the potentialities of other species of ligninolytic basidiomycetes. Platt *et al.* (1984) and Thurston (1994) used the ligninolytic fungi *Trametes* sp. and *Pleurotus* sp. for biodegradation studies. They reported that production of laccase by the fungi was highly related to lignin and dyes degradation.
Saranraj et al. (2010) investigated decolourization of direct azo dyes by fungi isolated from dye effluent. They concluded that the fungal isolates can be used as a good microbial source for waste water treatment.

Pavko (2011) reviewed some chemical engineering aspects of fungal decolourization and degradation of synthetic dyes, which could be applied during the research and transfer of dye bioremediation technologies to a large scale.

The ability of four different species of white rot fungi viz., Coriolus versicolor, Termetomyces sp., Pleurotus ostreatus and Schizophyllum commune to remove azo dyes from aqueous solutions were evaluated in batch culture under laboratory conditions by Sivasakthivelan (2013).