CHAPTER 1

INTRODUCTION

The defining feature of our planet, “water”, is crucial for all aspects of life. Ninety seven and a half percent of all water is found in the oceans. Of the remaining fresh water only one per cent is accessible for extraction and use. A healthy and functioning aquatic ecosystem provides us with a number of dazzling benefits like food, medicines, recreational amenity, shoreline protection, processing our waste and sequestering carbon. Continuous population growth, industrialization, food production practices, increased living standards and poor water use strategies lead to very high water crisis at the beginning of 21st century. Over half the world’s population faces water scarcity and nearly 900 million people still do not have access to safe water worldwide (UNDESA 2009). About 2.6 billion, almost half the population of the developing world do not have access to adequate sanitation (WHO/UNICEF 2010). Over 80 percent of people with unimproved drinking water and 70 percent of people without improved sanitation live in rural areas (DFID 2010).

As water plays a vital role in the sustenance of all life, it is a source of economic and political power (Narasimhan 2008) with water scarcity a limiting factor in economic and social development. Thus, water plays an essential role in the life of nation, its energy supply, infrastructure, economic growth, healthcare, education and culture which makes water the main concern for the national policies (RAE 2010). This precious natural resource is being contaminated every day due to rapid growth of population, urbanization and industrialization that ultimately make the environment polluted (Vasseur et al. 2000). Water is one on which a wide range of sectors from urban
development to food production and industry depend. Wastewater management or the lack of water has a direct impact on the biological diversity of aquatic ecosystems, disrupting the fundamental integrity of our life support systems. Thus it is essential that wastewater management is considered as part of integrated, ecosystem-based management that operates across sectors and borders, fresh water and marine.

Ground water is the prime source of drinking water in urban and rural areas of our country. The quality of drinking water in Indian cities has been deteriorated in the recent years mainly due to growth of population and improper disposal of waste water from industries (Venkatasubramani et al. 2007).

The presence of heavy metals in industrial and urban waste water is one of the major reasons of water and soil pollution (Edday et al. 2006). According to Altug and Balkis (2009) in developing as well as underdeveloped countries, the industrial effluents are released directly or indirectly into natural water resources, mostly without proper treatment, thus posing a serious threat to the environment.

Almost all the available industries (textile, dyeing, paper, plastic, leather, food, cosmetic etc.) release their untreated or partially treated waste water into municipal sewers or directly into nearby drains, rivers, ponds, lagoons or lakes. Such waste water disposal may cause acute damage to the quality of an aquatic bionetwork, receiving water bodies and the environment at large. The toxic effects of dyestuffs, organic compounds, acidic and alkaline contaminants from industrial establishments on the general public are widely accepted. Due to increasing public concern about environment, legal actions were taken on several small-scale industries to close. The significance of water to humans and other biological systems cannot be over emphasised. There are
numerous scientific and economic facts that, water shortage or its pollution can cause severe decrease in productivity and death of living species (Garba et al. 2010).

1.1 Tanning Industries

Tanning industry in India is one of the well developed industrial sectors (Sharma et al. 1996 and Naidu 2000). There are about 3000 major tanneries in India and approximately 314 million kilograms of skin are processed annually as reported by Camargo et al. (2003). According to a recent report by Murali and Rajan (2012) a total number of 2161 tanneries are located in India and spread across the states of Tamilnadu, West Bengal, Maharashtra, Punjab, Karnataka, Andhra Pradesh, Bihar and Uttar Pradesh and there are about 568 tanneries located in Tamilnadu.

Khaleelur Rahman (2010) reports that, Tamil Nadu is in the forefront in leather industry with an annual production of more than 1.2 billion sq. ft. of finished leather. It is about 60% share in total finished leather production of our country and 45% share in total export from India. The raw material processed per day is 500-1000 tons and annual turnover is more than Rs.10,000 crore. The main production centres for leather and leather products in Tamilnadu are Dindigul, Trichy, Erode, Pernambut, Ambur, Ranipet, Vaniyambadi, Chrompet and Puducherry. It contributes significantly towards exports, employment generation and occupies an important place in Indian economy (Ramasamy and Naidu 2000 and PREM 2004).

Sahasranamam and Buljan (2000) estimated that the effluent generated by tannery industry is about 75,000 m$^3$/day in India. Soyalsan and Karaguzel (2007) reported that the tanneries discharge 3000 litres of waste water per 100 kg of processed hides and the annual discharge of 9,420 kilolitres.
1.2 Process of Tanning

The process of converting raw hides and skins into leather is called tanning. The process can be explained under three headings:

- Pre-tanning (Preservation of hides and storage of skins and Beam house operations)
- Tanning and
- Post- tanning operations

The operations coming under the headings pre-tanning, tanning and post-tanning are depicted in figure 1.

I. Pre-tanning operations

Storage

Salting (dehydration)

Usually, raw hides and skins consist of 65% water and 30-35% proteins and fat which enhance bacterial degradation. In order to prevent the bacterial activity, the moisture content should be brought down to less than 30%. This is done by applying common salt sodium chloride to the hides/skins to the tune of 30-45% by weight.

Sorting

Based on their size, weight or quality hides and skins are sorted into several grades.

Trimming

Edges of the raw hides and skin (legs, tails and heads) are cut and removed during the sorting process.

Curing

Curing is a process that prevents the decomposition of hides and skins until the processes in the beam house begin. Popular methods of long-term curing are salting and drying. Methods for short-term curing (2- 5 days) are
Fig. 1. Process of tanning

Source: TGM for Tanneries, August 2010
cooling, using crushed ice or refrigerated storage and biocides. Curing is done in the abattoir, at the hide market or at the tannery.

**Storing**

Hides and skins are generally stored on pallets in ventilated or air-conditioned or cooled areas, depending on the method of curing chosen. From storage house the hides and skins are taken to the beam house.

**Beam house operations**

**Soaking**

The main purpose of this process is to remove the salt used during curing, re-hydrating the material and to get rid of unwanted materials such as dung, blood, soil *etc.* The duration of soaking may range from several hours to a few days. Additives such as surfactants, enzyme preparations and bactericides are the soaking agents applied depending on the type of raw material used. The process of soaking can be classified into three stages

- **Dirt Soaking** – Unwanted materials are removed by applying 300-400 % of water
- **Main Soaking** – At this stage, water, 0.2 % concentration soda ash and 0.05% concentration preservatives are used for re-hydrating the material.
- **Final soaking** – Only water is used for the washing purpose in this operation

**Liming**

Hair, flesh, partial fat and interfibrillary protein are removed by liming. The process of liming can be broadly classified into two parts *i.e.*, dehairing and re-liming.

- **Dehairing** – Lime (8-10 %) along with Sodium Sulphide (3 %) is applied to the skin to remove hair.
- Re-liming – To open up fibrous structure, lime, soda ash, caustic soda, etc., are applied. The pH of the skin being processed will rise to 12-12.5.

**Fleshing**

The excess flesh is removed manually or by using fleshing machines.

**De-liming**

This is a process to adjust the pH in between 8-8.5 in order to enhance the enzymatic activity, which converts some of the proteins into soluble forms. pH correction from 12-12.5 to 8-8.5 are done by using ammonium chloride in case of soft leather and ammonium sulphate in case of hard leather.

**Pickling**

Pickling is a process of correcting the pH suitable to the tanning operation and to prevent dehydration of the leather. For this, 80% water, 8-10% salts, 0.28-0.3% formic acid and 0.75 – 2% sulphuric acid (based on thickness of the skin) are applied.

**pH correction**

For vegetable tanning, a pH in between 4 and 4.5 is maintained whereas, pH in between 2.5 and 7.3 is maintained in case of chrome tanning.

**Prevention of swelling**

Salts to the tune of 8-10% are used in this process to prevent the swelling. Thus the dehydration takes place.

**II. Tanning operation**

The tanning process is of two types i.e., chrome tanning and vegetable tanning. Of the total leather production in India, more than 80% is based on chrome tanning and the rest is based on vegetable tanning.

**Chrome tanning**

7-10 % of Basic chromium sulphate or BCS \([\text{Cr}_2 (\text{SO}_4)_3]\) containing 25% \(\text{Cr}_2\text{O}_3\) and 25-30% sodium sulphate is used in chrome tanning. The pH is increased to 3.8-4.0 at the end of chrome tanning process which is called basification. The semi-finished leather after chrome tanning is called wet blue.
Vegetable tanning

Plant extracts are used for the purpose of tanning in this process. The pH falls down from 4-4.5 to 3-3.5. This process is free of any heavy metal use. But the leather developed from this process has comparatively weaker capacity of heat resistance and dye-holding.

Post-tanning operations

Post-tanning operations comprise of re-chroming of semi-finished wet blue leather, neutralization, dyeing, fat liquoring and finishing. In case of post-tanning of vegetable tanned semi-finished leather, the operations involved are semi-chrome tanning, neutralization, dyeing, fat liquoring and finishing. However the operations vary depending upon the final product.

Sammying

It is a mechanized process to remove excess moisture in the wet blue.

Splitting

After sammying, the material is split into required thickness using splitting machine.

Shaving and Trimming

The semi-finished leather is leveled using the shaving machine.

Re-chroming

Depending on the quality of wet blue, re-chroming is carried out to improve the chromium content in the leather.

Semi-chroming

In case of vegetable tanned semi-finished leather, chrome tanning is given depending on the final leather quality.

Neutralization

pH is adjusted to 4.5-6.5.

Dyeing

The leather is coloured using dyes such as anionic dyes, acid dyes, direct, metal complex compounds and basic dyes.
Fat-liquoring

Natural/synthetic oils are applied for fat liquoring, thereby imparting softness to the leather.

Finishing

Phenolics, melamine, acrylics, polymers, naphthalene etc., are used for finishing to impart fullness to the leather.

Operations carried out in the beam house, tanyard and post-tanning areas are often referred to as wet processes, as they are performed in processing vessels such as drums. After post-tanning, the leather is subjected to dry finishing operations.

1.3 Input Vs Output in the Tannery Process

The major inputs such as water, chemicals in each sectional operation starting from soaking, liming, fleshing, deliming, pickling, vegetable or chromium tanning etc., till finishing and the mode of operation and equipment used such as pits, paddle, drums, type of machine operations and the waste discharges from each sectional operation such as wastewater fleshings, waste trimmings and the major constituents in the wastewater in terms of TDS, COD and BOD are given in figure 2.

The characteristics of tannery waste water vary widely depending on the nature of the tanning processes (Tunay et al. 1995). The tannery waste is always characterized by a dark brown colour (Kongjao et al. 2008) due to the presence of dyes, high BOD, high pH and high dissolved solids. The waste water from the leather tannery contains mainly dyes, chromium, zinc, copper, sulfides, carbonates, sodium and many other toxic organic and inorganic compounds (Nouri et al. 2009).
Fig. 2. Input vs output in the tannery process

Source: TGM for Tanneries, August 2010
1.4 Chromium in Leather Tanneries

The major chemical constituent of the waste from the leather tanning industry is chromium. Cr (III) is efficiently used as tanning agent in leather industry. A great deal of chromium ions are released in tanning, dyeing and fat liquoring floats. In fact, tannery wastes are ranked as the highest pollutants of chromium among all the industrial wastes (Kumar Omprakash et al. 2013).

Environmental pollution problems are caused by discharge of untreated effluent from tanneries with high chromium content as chrome tanning is widely practiced in Tamil Nadu. In chrome tanning 60% of chromium applied is in the form of Basic Chromium Sulphate salts (BCS) which would be taken up by the leather and the rest is discharged as waste in the effluent. In chrome tanning 276 chemicals including 14 heavy metals are used. Approximately 32,000 tonnes of BCS are used annually in Indian tanneries (Ramasamy et al. 2000). Kareem (1998) estimated that the concentration of chromium in the discharged effluent ranges from 2000 ppm to 5000 ppm, which causes an annual loss of 2000 to 32,000 tonnes of chromium.

Chromium is the seventh most abundant element on earth and exists in several oxidation states from Cr (II) to Cr (VI). This pollutant is mainly introduced into the aquatic systems from the effluents of leather processing units as a result of chrome tanning of leather, mostly without proper effluent treatment (Shakoori et al. 2000; Aswathi and Rai 2005 and Franco et al. 2005). Among the different forms of chromium, Cr (III) is easily adsorbed in soils and waters, whereas Cr (VI), which is the toxic form, is not readily adsorbed and is soluble (Kotas and Stasicka 2000). Toxic kinetics of Cr (VI) was studied by Vankar and Bajpa (2008) and Vankar et al. (2009). They found that Cr (VI) has higher rate of penetration into biological membranes as compared to Cr (III) and the metal is highly carcinogenic. Malfunction of kidney, liver and lungs
would be due to the exposure to chromium (Korkina 2007). Accumulation of toxic metals such as Cd, Cr, Cu, Hg and Zn in humans has also been well documented by Thiele (1995).

In humans, exposure to Cr (VI) salts for periods of 2 to 26 years has been implicated as a cause of cancer of the digestive tract. In plants, high levels of chromium supply can inhibit seed germination and subsequent seedling growth. Cr (VI) has posed acute and chronic health risks to animals and humans, since Cr (VI) is acutely toxic, mutagenic, carcinogenic and teratogenic (McLean and Beveridge 2001).

Chromium was found in many specimens of blood and teeth of human beings and animals. It causes dermatitis on the skin, bleeding, scabbing, dryness, superficial ulceration on the nasal mucosa, inflammation, lung carcinoma and liver injury in humans. Toxic effect of chromium in animals includes stunted growth, thickening of alveolar walls, proliferation of cells along the blood vessels etc. (Shankar et al. 2007).

1.5 Dyes as Effluent Contaminant

A dye is a coloured substance that can be applied in solution or as dispersion in a substrate, giving a coloured appearance. The substrate may be textile fibers, paper, leather, fur, plastic material, wax, cosmetic base, food or pharmaceutical products. The common property of dyes is to absorb light due to the chromophore, a part of the molecule responsible for its colour. However, the variation in the structure is enormous and many thousand different dyes are produced for commercial use. In general, dyes can be classified according to their chemical structure, particularly chromophore and the method of application (Raffi et al. 1997 and Hao et al. 2000).
It is estimated that $8 \times 10^5$ tonnes of dyes (10,000 different types of dyes and pigments) are produced worldwide annually (Walker and Weatherly 1997). Some of them are dangerous to living organisms due to their possible toxicity and carcinogenicity. About 10% of the above mentioned amount is lost in waste water, which justifies the concern about the environment. Different types of synthetic dyes used each year in leather industries are lost during manufacturing and processing operations and 20% of these dyes enter the environment through effluents (Abadulla et al. 2000). Such coloured organic substances, dyes are responsible for the high biological oxygen demand (BOD) and chemical oxygen demand (COD) of the effluents. These dyes along with chromium and sulphates get mixed with water and are discharged from the tannery which pollutes the ground water permanently and make it unfit for drinking, irrigation and general consumption (Bernal et al. 2006).

The environmental concern of these potentially carcinogenic pollutants in contaminated water has drawn the attention of many researchers (Abo-Farha 2010 and Surana et al. 2011). Several conventional physicochemical methods such as electrochemical treatment, ion exchange, precipitation, reverse osmosis, evaporation and sorption are used to treat tannery effluents. The degradation of synthetic dyes in waste streams can be performed with various technologies, which can be subdivided into four main groups: 1) physical 2) chemical 3) electrochemical and 4) biological processes (Robinson et al. 2001 and Singh 2006). However, these methods are very expensive and present difficulties in the elimination of high quantities of polluting substances in tannery effluents (Kadirvelu et al. 2002; Srivastava and Thakur 2006 and Sirajuddin et al. 2007).

Hence there is an urgent need to determine the pollution level in waste waters from these industries and the removal of heavy metals and dyes from the effluent discharged by cost effective and eco-friendly methods.
1.6 Bioremediation

The term biodegradation is often used in relation to ecology, waste management and mostly associated with environmental remediation or simply bioremediation (Marinescu et al. 2009). Bioremediation process can be divided into three phases or levels. First, through natural attenuation, contaminants are reduced by native microorganisms without any human augmentation. Second, biostimulation is employed where nutrients and oxygen are applied to the systems to improve their effectiveness and to accelerate biodegradation. Finally, during bioaugmentation, microorganisms are added to the systems. These supplemental organisms should be more efficient than native flora to degrade the target contaminant (Diez 2010). A feasible remedial technology requires microorganisms being capable of quick adaptation and efficient use of pollutants of interest in a particular case in a reasonable period of time (Seo et al. 2009). Many factors like the genetic potential of the microorganisms, certain environmental factors such as temperature, pH and available nitrogen and phosphorus sources seem to determine the rate and the extent of degradation by microorganisms to use pollutants as substrates or cometabolize them (Fritsche and Hofrichter 2008).

Biodegradation is described in association with environmental bioremediation. It is defined as the biologically catalysed reduction in complexity of chemical compounds (Alexander 1994). In most cases the term biodegradation is used to describe almost any biologically mediated change in a substrate (Bennet et al. 2002). When biodegradation is complete, the process is called "mineralization".

Understanding the process of biodegradation requires an understanding of the microorganisms that make the process work. The microbial organisms transform the substance through metabolic or enzymatic processes. Several
microorganisms including fungi, bacteria and yeasts are involved in biodegradation process. Algae and protozoa reports are scanty regarding their involvement in biodegradation (Das and Chandran 2011). Biodegradation processes vary greatly but frequently the final product of the degradation is carbon dioxide (Pramila et al. 2012). Organic material can be degraded aerobically with oxygen or anaerobically without oxygen (Mrozik et al. 2003).

Biodegradable matter is generally organic material such as plant and animal matter and other substances originating from living organisms. Artificial materials that are similar to plant and animal matter are also used by microorganisms. Biodegradation is nature's way of recycling wastes or breaking down organic matter into nutrients that can be used and reused by other organisms. In the microbiological sense, "biodegradation" means the decaying of all organic materials carried out by other living organisms. These forms mainly constitute bacteria, algae, yeast, fungi etc.

In the last few decades, highly toxic organic compounds have been synthesized and released into the environment for direct or indirect application over a long period of time. Fuels, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), pesticides and dyes are some of these types of compounds. Some other synthetic chemicals like radionuclides and metals are extremely resistant to biodegradation by native flora compared with the naturally occurring organic compounds that are readily degraded upon introduction into the environment. Bioremediation and biotransformation methods make use of naturally occurring microbial catabolic diversity (Lesley and Penny 2012).

Bioremediation is a process which involves degradation of toxic pollutants to non-toxic products. It utilizes living organisms for the treatment of wastes and reducing the rate of pollution. Bioremediation is comparably
superior to any conventional technologies because of its effectiveness and low cost in implementation and the end products are non-hazardous (Dresback et al. 2001). More et al. (2001) have suggested that bioremediation will be a cleaner way to treat the effluents as they operate under milder conditions with minimum generation of byproducts.

Bioremediation has developed from the laboratory to a fully commercialized technology over the last 30 years in many industrialized countries. A successful bioremediation scheme relies on the management of microbial populations capable of catabolising the contaminants. Bioremediation techniques are more economical than traditional methods such as incineration. Some pollutants can be treated on site thus reducing exposure risks for the workers involved. It also reduces the chances of transportation accidents. Since bioremediation is based on natural attenuation, the public considers it more acceptable than other technologies (Srinath et al. 2002; Jianlong et al. 2004 and Zouboulis et al. 2004).

Use of biological materials for heavy metal removal or recovery has gained importance in recent years due to their efficient performance and low cost (Volesky 1987; Gadd 1990; Reed and Nonavinakere 1992; Mattuschka and Straube 1993; Kapoor and Viraraghavan 1997; Atwood et al. 2002 and Di Palma et al. 2003). There is a growing interest towards the research of new, economical and easily available biosorbents such as algae, bacteria, fungi and yeast which were found to have potentialities in solving environmental problems (Yan and Viraraghavan 2003). Use of microorganisms for removal of toxic heavy metals from effluents and colour from dye are also reported by Fu and Viraraghavan (2002).
1.7 Microbes in Bioremediation

Among the living organisms, microbes are more preferred due to their easiness in handling and their biomass and growth can be done in a controlled environment. Further, strain improvement and higher efficiency can be easily manipulated when microbes are used in targeting the removal of chromium and dyes from effluents. Bacteria and fungi are the chief agents for biodegradation, while algae, diatoms, some plants and animals also metabolize chemicals (Alexander 1981). Microorganisms can play an important role in the detoxification and removal of heavy metals from polluted environments (Gadd et al. 1987; Mullen et al. 1989; Gupta et al. 1992 and Atkinson et al. 1998). Microbial degradation of azo dyes has been reported using different microorganisms like bacteria, yeasts and white rot fungi (Jadhav et al. 2007).

The accumulation of chemicals within the microbial biomass is termed as biosorption and can take place on living or dead biomass. Bioadsorption has many applications, which involve the detoxification of hazardous substances by means of microbes and plants. This process is also characterized as less disruptive and can be often carried out on site, eliminating the need to transport the toxic materials to treatment sites (Gavrilescu 2004). Recently microbial systems like fungi, bacteria and algae have been successfully used as adsorbing agents for removal of heavy metals (Tobin and Roux 1998 and Munoz et al. 2006).

Dead microbial biomass can be used as an efficient adsorbent, especially when it contains a natural polysaccharide chitin and its derivative chitosan in the cell walls. Chitosan, a cell wall component of many industrially important fungi has a unique molecular structure with a high affinity for many classes of dyes (Kurek et al. 1982; Gadd 1988; Brierley 1990; Volesky 1994 and Chen et al. 2000).
1.8 Fungi in Bioremediation

The high tolerance towards metals, high wall-binding capacity and intracellular metal uptake capabilities make the fungi more suitable than bacteria for biodegradation studies (Volesky and Holan 1995). They are the decomposers in the global cycle of life and death. They have an ability to break down the complex organic substances into simpler substances. They are ubiquitous and found in soil, aquatic environments and disseminate through the air. They are also reported as endobionts. They often are found to function along with bacteria and other microorganisms either as symbionts or as co-colonizers. They are easy to culture on a large scale by both liquid and solid fermentation methods. The harvesting is easy and enough biomass will be obtained for further processing. Fungi can grow on the surface of an inorganic vector during culture. This can be easily distributed in the desired environment as a catalyst. Bai and Abraham (1998) and Merrin et al. (1998) documented the potential of fungal biomass as biosorbent for the removal of heavy metals from polluted water.

Fungi are considered as the efficient dye reduction source. Due to the fungal oxidative mechanisms it is possible to avoid the formation of hazardous anilines formed by reductive cleavage of the azo dyes (Zheng and Obbard 2002).

1.9 Importance of Native Mycotic Flora in Bioremediation

It is a known fact that application of native flora on removal of heavy metals or dyes as pollutants is better when compared to other strains brought from different environment. As reported by Radha (1995), the presence of native microbes in tannery effluent would be successfully exploited to remove the pollutants as they posses better tolerance limit and acclimatized to the toxic
level of heavy metal concentration and dyes used in such industries. There are only limited number of studies (Jamal 2002) which have been carried out systematically to isolate the native flora and application of the same on reduction of chromium and dyes used in leather tannery industries (Bai and Abraham 2002).

1.10 Objectives of the Present Study

There is no authenticated study on diversity of fungi from the tannery effluent, bioadsorption of chromium and biodegradation of dyes from the tannery effluent using native fungi of Ambur, Chrompet, Ranipet and Vaniyampadi in Tamil Nadu. Hence the present study has been carried with the following objectives

- To study the diversity of fungi present in the leather tannery effluents from Ambur, Chrompet, Ranipet and Vaniyampadi.
- To identify the dominant fungi from native flora for mass culture.
- To assess the bioadsorption ability of the specific native fungal strains in the adsorption of heavy metal chromium under laboratory conditions.
- To understand the ability of the native fungi in the biodegradation of selected dyes.
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, Naraikhedha, 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 (Bhanoori 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 *Cunninghamella 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 (Ollikkka 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).