2.1 GENERAL

Treatment of textile dyeing industries has been a challenging task yet now in many parts of the world. The problem in the treatment of textile dye industries are majorly the removal of pollutants like Colour, BOD, COD and TDS. Many researchers have worked in the treatment of textile dye effluent from laboratory model to pilot scale model for the removal of colour. Colour present even at a very low concentration of 1mg/L will be easily visible. Colour is released in a greater percentage from the dyeing process of textile industries. Coloured wastewater from textile industries is rated as the most polluted in almost all industrial sectors (Andleeb et al., 2010).

The presence of very small amounts of dyes in water is highly visible and affects the aesthetic merit, water transparency and gas solubility in lakes, rivers and other water bodies (McKay et al., 1979) and degradation products of these dyes are often carcinogenic (Kim et al., 2003). The treatment of textile waste effluents is still a major environmental concern because of synthetic dyes which are difficult to be removed by conventional physical and chemical technologies (Zhang et al., 2004) such as membrane filtration, coagulation, precipitation, flotation, adsorption, ion exchange, chemical reduction, ultrasonic mineralization, electrolysis and advanced chemical oxidation (Gogate and Pandit, 2004; Kang et al., 2010). Some of these methods are effective but have
inherent drawbacks such as high cost, intensive energy requirements, formation of hazardous by-products and generation of sludge which causes secondary pollution (Do et al., 2002; Verma et al., 2003; Maier et al., 2004; Ramya et al., 2007; Dayaram and Dasgupta, 2008). Biological treatments have been the final solution for treating the textile dyeing effluent due to their eco friendly nature and cost effectiveness which overcomes the physiochemical methods employed so.

2.2 TEXTILE MANUFACTURING PROCESS

Manufacturing process of textile industries are majorly a wet process. It consumes large amount of water for its processes. The flowchart showing the manufacturing process of the textile industries is shown in the Figure 2.1.

![Figure 2.1 Flow Diagram of textile manufacturing process](image-url)
More commonly the wastewater is generated in the wet processes of the textile dyeing industries which are listed below and explained. The major pollutant types, the process of their origin and the chemicals used in the process are presented in the Table 2.1.

- Sizing
- Desizing
- Scouring
- Bleaching
- Mercerizing
- Dyeing
- Printing
- Finishing.

**Sizing**

Sizing is carried out before the weaving process to increase the breaking strength, binding nature and smoothness of the yarn, to reduce yarn breakages. Starch normally used as the sizing material because of their low cost but the high BOD tend to change the starch to synthetic polymers like Polyvinyl alcohol (PVA) and carboxyl methyl cellulose. Wastewater generated from the sizing process was characterized by its high BOD, COD, sizing compounds and suspended solids.
Desizing

Desizing, either with acid or enzymes removes size from the fabric, so that chemical penetration of the fabric in later stages is not inhibited. Desizing effluents have very high organic concentrations, contributing 40-50% of the total organic load from the preparatory sequences. Gums and PVA may be removed by a simple hot wash but starch and its derivatives have to be made soluble by soaking with acids, enzymes or oxidants before being removed by a hot wash.

Scouring

Scouring is carried out to remove impurities that are present in cotton. This is usually done at high temperatures with sodium hydroxide and produces strongly alkaline effluents with high organic loads. They wastewater from this process is characterized by its dark in colour and high concentrations of TDS oil and grease. Common scouring agents include detergents, soaps, alkalis, antistatic agents, wetting agents, foamers, defoamers and lubricants.

Bleaching

Bleaching is used to whiten the fabrics and yarns using sodium hypochlorite or hydrogen peroxide. Many cotton processing factories in India use sodium hypochlorite as it is cheaper than hydrogen peroxide. However, this is highly toxic and is now strictly limited or banned in many countries. It can also break down to form absorbable organic halogen compounds, which are both toxic and carcinogenic. Bleaching generates effluents with a low organic content, high TDS levels and strong alkalinity (pH 9-12).
Mercerizing

In this process, the cotton yam or fabric is treated with an alkali (sodium hydroxide) to improve luster, strength and dye uptake. It also removes immature fibers. The process is normally carried out on dry fabric; wet mercerizing reduces the steam consumption, but requires stringent control of the operational parameters, such sodium hydroxide concentration. The rinse wastes are alkaline, high in inorganic solids and caustic alkalinity, and low in BOD. With the increasing trend toward cotton-polyester blends, much less mercerizing is being carried out.

Dyeing

Dyeing is the most complex of the wet processes which includes hundreds of dyes and auxiliary chemicals such as fixing agents, acids, alkalis etc.., In 1856 William Henry Perkin discovered the world’s first commercially successful synthetic dye, towards the end of the 19th century ten thousand new synthetic dyes was developed and manufactured. The purpose of dyeing is to transfer the colour of the dye solution to the fiber as for the requirement demanded. Mostly synthetic dyes are used for the dyeing process. Based on the application dyes are classified as Acid dyes, Basic dyes, Direct dyes, Mordant dyes, Reactive dyes, Vat dyes and Sulphur dyes. Various dyeing methods like Jigger, Winch, Beam, Jet, Padding, Soft flow, Continuous range and Thermosol were carried over depending upon the nature of the material and required quality. On the basis of the application of dyeing is classified as yarn dyeing and fabric dyeing. About half of the total volume of wastewater is generated from
dyeing process only. Generally dyeing effluent is characterized by their dark colour, high BOD, COD, Suspended solids and Dissolved solids.

**Printing**

Printing is a process that is used for applying colour to a fabric. Unlike dyeing, it is usually carried on prepared fabric where it is applied to specific areas to achieve a planned design. The colour is applied to the fabric and then treated with steam, heat or chemicals to fix the colour on the fabric. The most commonly used printing techniques are:

- Pigment printing, commonly used for all fabric types.
- Wet printing uses reactive dyes for cotton and generally has a softer feel than pigment printed fabrics.
- Discharge printing creates patterns by first applying colour to the fabric and then removing selected areas.
- Final washing of the fabric is carried out to remove excess paste and leave a uniform colour.

**Finishing**

The finishing process imparts the final aesthetic, chemical and mechanical properties to the fabric as per the end user requirements. Common finishing processes include:

- Wrinkle Resistant/Cr ease Retentive - using synthetic resins.
- Water / Oil Repellent - using silicones and other synthetic materials like fluorocarbon resins).
Flame Retardant - most commonly carried out on synthetic fabrics, by copolymerization of the flame retardant into the fabric itself; introduction of an additive during processing; application as a textile finish. Natural fibers such as cotton can only be made flame retardant by applying a chemical finish.

Mildew Resistance - using hazardous substances such as mercury, copper, arsenic and chlorinated phenols.

Table 2.1 Pollutant types of textile wastewater, origin process and chemicals used for the process (Delée et al., 1998)

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Chemical types</th>
<th>Process of origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic load</td>
<td>Starches, enzymes, fats, greases, waxes, surfactants and acetic acid</td>
<td>Desizing, Scouring, Washing, Dyeing</td>
</tr>
<tr>
<td>Colour</td>
<td>Dyes, scoured wool impurities</td>
<td>Dyeing, Scouring</td>
</tr>
<tr>
<td>Nutrients (N, P)</td>
<td>Ammonium salts, urea, phosphate based buffers and sequestrants</td>
<td>Dyeing</td>
</tr>
<tr>
<td>pH and salts</td>
<td>NaOH, mineral/organic acids, sodium chloride, silicate, sulphate, carbonate</td>
<td>Scouring, Desizing, Bleaching, Mercerising, Dyeing, Neutralisation</td>
</tr>
<tr>
<td>Sulphur</td>
<td>Sulphate, sulphite and hydrosulphite salts, sulphuric acid</td>
<td>Dyeing</td>
</tr>
<tr>
<td>Toxic compounds</td>
<td>Heavy metals, reducing agents (sulphide), oxidising agents (chlorite, peroxide, dichromate, persulphate), biocides, quaternary ammonium salts</td>
<td>Desizing, Bleaching, Dyeing, Finishing</td>
</tr>
<tr>
<td>Refractory organics</td>
<td>Surfactants, dyes, resins, synthetic sizes (PVA), chlorinated organic compounds, carrier organic solvents</td>
<td>Scouring, Desizing, Bleaching, Dyeing, Washing, Finishing</td>
</tr>
</tbody>
</table>
2.3 CHARACTERISTICS OF TEXTILE DYE INDUSTRY WASTEWATER

Textile dye wastewater is characterized by its Colour, high BOD, high TDS, COD, Suspended solids, Alkaline pH and toxic compounds. Industrial dyes have been designed and synthesized to be highly resistant to washing, chemical agents including solvents and to the action of sunlight, water and microbial attack (Meenu Chhabra et al., 2008; Mohorcic, M et al., 2006; Wesenberg, D et al., 2003). In aquatic systems, the dyes undergo various reactions and the variations in their chemical structures results in the formation of new xenobiotic compounds, which are toxic than their raw compounds (Khelifi, E. et al., 2008; Patil, P.S et al., 2008). Major wet process involved in the textile industries and their wastewater characteristics are tabulated in the Table 2.2.

Table 2.2 Major wet processes of textile industries and their wastewater characteristics

<table>
<thead>
<tr>
<th>Wet Textile Process</th>
<th>Wastewater Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sizing</td>
<td>High BOD, High Solids</td>
</tr>
<tr>
<td>Desizing</td>
<td>High BOD, High Solids</td>
</tr>
<tr>
<td>Scouring</td>
<td>High BOD, High Alkalinity</td>
</tr>
<tr>
<td>Bleaching</td>
<td>High BOD, Alkaline pH</td>
</tr>
<tr>
<td>Mercerizing</td>
<td>Alkaline pH, low BOD</td>
</tr>
<tr>
<td>Dyeing</td>
<td>Colour, High BOD, High COD, High Solids, Alkaline pH</td>
</tr>
<tr>
<td>Finishing</td>
<td>High BOD</td>
</tr>
</tbody>
</table>
2.4 WASTEWATER GENERATION

The requirement of water is important to assess the quantity of effluent, as the entire water used in the process of textile dyeing industries will result in waste streams. Requirement of water for various processes involved in the textile dyeing industries will vary on the basis of the material (yarn and fabric), type of dye used, type of shade required and the method of dyeing. The water requirement for dyeing ranges between 35 to 175 L/kg of cloth product. The effluent generation of the dyeing process ranges between 30 to 170 L/kg of cloth product. The quantity of the wastewater generated varies on the usage of the dyes, equipments, chemicals and application of dyes.

2.5 DYSES IN THE TEXTILE DYEING PROCESS

Majorly synthetic dyes are used in the dyeing process of the textile industries. Synthetic dyes have many structural varieties, such as, acidic, basic, disperse, azo, diazo, anthroquinone based and metal complex dyes, that fall into either the cationic, nonionic or anionic type. Anionic dyes include the direct, and the most problematic water-soluble acid and reactive dyes. Nonionic dyes refer to disperse dyes that do not ionize in aqueous medium and some of them have the ability of bioaccumulation. Whereas anthroquinone based dyes are the most resistant to degradation due to their fused aromatic ring structure (Robinson et al., 2001).

The color of dye is combined effects of chromophores, delocalized electron system with conjugated double bonds, and auxochrome – electron
withdrawing or electron donating substituent that enhance the color of chromophore by changing the overall energy of electron system. Some of the important chromophores are –N= N- , -C= O, -NO2 and quinoid groups, and important auxochromes are -NH3, -OH, -SO3H and -CO2H. Both chromophore and auxochrome increase the bath chromic effect – shifting adsorption bands to longer wavelength, on a conjugated system of dye. In addition to enhancing the chromophore in production of color, auxochromes are also responsible for the solubility of dye and increase its reactivity towards fibers.

The chromophores in anionic and non-ionic dyes are mostly azo groups or anthroquinone type. Toxic amines result when azo groups undergo reductive cleavage.

Reactive dyes are azo-based chromopores that contain different types of reactive groups such as vinyl sulfone, chlorotriazine, trichloropyrimidine, difluorochloropyrimidine. In contrast to other classes of dyes, they form covalent bonds to the textile fibers such as cotton. The uses of reactive dyes are highly favored in the textile industries owing to their bright color, water fast, simple application techniques with low energy consumption and, thus reactive dyes are among the dyes most commonly in use today (Aksu, 2005). Reactive dyes are used primarily on cotton and rayon. They are highly soluble in water and with the help of large amount of salt; the exhaustion of the dyes is improved. Metals found as integral parts of the dye chromophores comprise mainly cobalt, copper, and chromium. However, some dyes have low-level metal impurities that are
present incidentally, rather than necessity in terms of functionality and color. When mercury-based compounds are used as catalysts in dye manufacturing, there is a possibility of its presence as trace residue.

Industrial textile dyes have been designed and synthesized to be highly resistant to washing, chemical agents, including solvents, and environmental factors, such as the action of sunlight, water and microbial attack. There are currently more than 10,000 different textile dyes commercially available in the world market (Campos et al. 2001; Keharia and Madamwar 2002). A large portion of dyes, that is lost during the dyeing process, could remain more or less intact, given the fact that both traditional physicochemical and biological wastewater treatments are unable to perform an acceptable degradation and decolourization of the majority of the available dyes (Shaul et al., 1991; Gill et al., 2002). Weber and Stickney (1993) have reported that the half-life of reactive blue 19 is 46 years at 25ºC and pH 7.0. In addition, reactive dyes typically have poor fixation to fabrics, and dye concentrations up to 1,500 mg/L could be found in the liquor that is discharged into the sewers (Pierce 1994). Moreover, about 90% of reactive dyes persist after being subjected to activated sludge treatment.

2.6 IMPACT OF TEXTILE DYE EFFLUENT TO THE ENVIRONMENT

Wastewater from the textile dye industries is a significant source of environmental pollution. Textile wastewater includes much type of dyes, detergents, insecticides, pesticides, sulphate, heavy metals, solvents, inorganic
salts, fibers, carcinogen and mutagenic agents. The presence of very small amounts of dyes in water is highly visible and affects the aesthetic merit, water transparency and gas solubility in lakes, rivers and other water bodies (McKay, 1979) and degradation products of these dyes are often carcinogenic (Kim et al., 2003). Apart from the aesthetic problems created when coloured effluents reach the natural water currents, dyes strongly absorb sunlight, thus impeding the photosynthetic activity of aquatic plants and seriously threatening the whole ecosystem (Slokar et al., 1998). Dyes in the water undergo various reactions and the variations in their chemical structures result in the formation of new xenobiotic compounds, which is toxic than their parental compounds.

Environmental impacts caused due to the textile dye industries effluent without proper treatment are very high, with respect to the concentration of dye and exposure time, dyes can have acute or chronic effects on exposed organisms. Impacts due to textile dye industries are listed below,

- Affects the aesthetic appearance of the receiving natural aquatic bodies.
- Affects the aquatic ecosystem by reducing the photosynthetic activities of the aquatic plants and the livelihood of the aquatic species like fishes surviving in it leading to the damage of the food chain of the aquatic ecosystem.
- It alters the characteristics of the receiving natural water bodies and the ground water by increased pH, high TDS, high BOD, high COD, Colour and Suspended solids which makes the water bodies unfit for the
irrigation purposes and reduces the crop production of the lands which depends on those water bodies.

- Many dyes and their breakdown products are carcinogenic, mutagenic and toxic to human life by affecting the persons in contact and use. Diseases like dermatitis, respiratory problems and irritations to eyes, skin, mucous membrane and respiratory tract. Cancers, liver diseases, kidney problems in the humans are the health hazards of the textile dye industries effluent.

### 2.7 TREATMENT METHODS

Textile dyeing process is a very complex process which uses various dyes and auxiliary chemicals. The amount of wastewater varies widely depending on the type of process operated in the textile dye industry. The problem related to the huge quantity of wastewater generated from textile dye industry is somewhat met with the adaptation of modern equipments in the dyeing process such as soft flow equipments.

Problem associated with the wastewater is towards its quality only i.e., with Colour, TDS, COD, Suspended solids and Toxic chemicals released which exceeds the permissible limits. Many treatment methods are available for removing the colour and biodegradable organics. Treatment methods like Physicochemical methods and Biological methods are the widely applied methods in the treatment process of the textile dye industries. Moreover Biological methods are preferred for their cost effectiveness and environment
friendly nature. Biological methods are the popular and attractive technology that utilizes the metabolic potential of microorganisms to clean up the environment.

2.7.1 Physicochemical treatment methods

Membrane filtration, Coagulation, Precipitation, Flotation, Adsorption, Ion exchange, Chemical reduction, Ultrasonic mineralization, Electrolysis, Ozonation and Advanced chemical oxidation are the examples for the Physicochemical methods available for the decolourization process. All the Physicochemical methods showing very good efficiency in the decolourization of the textile dye effluents when compared to the biological treatment methods (Sen & Demirer., 2003; Sadrghayeni et al.,1998; Treffry-Goatley et al., 1983; Tinghui et al., 1983; Chakraborty et al., 2003; Jain et al., 2003; Rossignol et al. 2000; Freger et al., 2000; Knauf et al., 1998; Mietton-Peuchot et al., 1997; Kelly & Kelly, 1995; Aguilar et al., 2005; Gaehr et al., 1994; Zouboulis et al., 2004; S. Lidia etal.,2001; L.Stanislaw et al.,2001; Al-kdasi et al., 2004; F.S. Mehmet et al.,2002; Nesheiwat & Swanson, 2000; Park et al., 1999).

Due to their hazardous by-products, cost and sludge production the Physicochemical methods are not preferred mostly in the treatment of textile dyeing industries (Muruganandham and Swaminathan et al., 2004; Forgas et al., 2004 ; Andre et al., 2007;Mohan et al.,2007;Allegre et al.,2006; Stanislaw et al., 2001; Kapdan and Kargi, 2002 ; Marco and Jose, 2007; Ramakrishna and Viraraghavan, 1997; Southern, 1995).
2.7.2 Biological treatment methods

The biological decolourization processes are aerobic activated sludge process, rotating biofilm reactors, aerobic or anaerobic packed-bed reactors, aerobic or anaerobic reactors, fluidized-bed reactors, aerobic or anaerobic sequential batch reactors, continuous-flow reactors and anaerobic batch reactors (Banat et al., 1996; Shaul et al., 1991; Lin et al., 1994; Seshadri et al., 1994). Biological treatment of wastewater uses either aerobic or anaerobic microorganisms used to degrade organic loads. An Aerobic process uses oxygen as the main electrons acceptor, thereby causing the oxidation of organic compounds. It transforms complex molecules into simpler substances. This respiratory metabolism liberates the necessary energy for maintenance and growth of microbial cells. The total oxidation of organic compounds can be achieved in the aerobic process.

Oxidation in the anaerobic process is only partial and occurs in the absence of oxygen. Among low-cost, viable alternatives available for effluent treatment and decolourization, the biological systems are recognized by their capacity to reduce BOD and COD by conventional aerobic biodegradation (Sandhaya et al., 2005; Balan et al., 2001; Dubin et al., 1975; Chung KT et al., 1992). Colour removal under anaerobic condition could be by biodegradation of dyestuff by azoreductase activity (Crailiell et al., 1995) or by non-enzymatic azo reduction of dyestuff (Flores et al., 1997; Brown et al., 1993). The azo reductase cleavage of azo bonds may result in formation of aromatic amines, which induces melanomas in humans and experimental animals (Chung et al., 1992;
Problem with anaerobic colour removal is the reverse colourization of anaerobic degradation products upon exposure to oxygen. This could be because of unstable characteristics of biodegradation products, aromatic amines, which deteriorate to give colour (Knapp and Newby, 1995; Chinwetkitvanish et al., 2000).

The development of microbial biofilm has been the subject of many investigations usually to elucidate a large number of undesirable effects associated with biofilm growth. Biofilm can be advantageously used for industrial purpose as in wastewater treatment. In that purpose, many different biofilm reactors have been designed to answer the variety of research questions and industrial applications. FBR is one of the efficient biofilm reactors attaining the greater attention of the many industries in their wastewater treatment process. FBR, the space and power saving technology is a better alternative to conventional wastewater treatment plants that are large-sized, power intensive and require a lot of monitoring.

2.8 FBR

The wide variety and large quantity of chemical compounds found in the industrial wastewaters are responsible for most of the environmental pollution of aquatic bodies. In view of the extensive contamination of the environment by persistent and toxic chemical pollutants originating from industrial wastewaters, it is imperative to develop cost effective and efficient methods. FBR was the reactor used for the cracking of petroleum products in the early 1930 and later
for the production of gasoline and many refinery products by their feature of the moving beds and the properties of behaving like fluid. In the early 1970 and 1980 FBR find their applications in the wastewater treatment for the removal of phenol compounds. FBR has generated a lot of interest in the recent period for wastewater treatment.

The major advantage of FBR over other biodegradation systems is a higher biomass concentration and a higher mass transfer resulting in a higher rate of biodegradation. The application of the FBR makes it possible to achieve phase homogeneity and larger solid–liquid contact area. These characteristics of a FBR enable an operation at a high volumetric loading, a fact that makes a fluidized bed an appropriate choice for treatment of textile dye effluents. A higher biomass concentration than suspended, a smaller pressure drop than fixed bed biofilm systems, no bed-clogging problems, small reactor volumes and low external mass transport resistance are some advantages of the fluidized bed biofilm systems when compared to other biological processes (Yu et al., 1997).

2.9 WRF

WRF are filamentous fungi which inhabit the wood of dead trees, most of them belong to the Basidiomycetes type and some are in the Ascomycetes group. The characteristic feature of white rots is their ability to degrade lignin within lingo cellulosic substrates. White rots are called because of the white appearance of the rotted wood in which the lignin was degraded. WRF are key regulators of the global C-cycle. Their LME, i.e., Manganese peroxidases (MnP),; Lignin
peroxidases (LiP), and Laccases (Lac), are directly involved not only in the
degradation of lignin in their natural lingo cellulosic substrates (Becker and
Sinitsyn, 1993; Hatakka, 1994) but also in the degradation of various xenobiotic
compounds (Barr and Aust, 1994; Pointing, 2001; Scheibner et al., 1997)
including dyes (Glenn and Gold, 1983; Pasti-Grigsby et al., 1992; Paszczynski et
al., 1992; Spadaro et al., 1992). Some WRF produce all three LME while others
produce only one or two of them (Hatakka, 1994).

WRF species degrade many xenobiotic compounds with a wide variety of
structures. Most of the aromatic structures are degraded by these WRF species.
The various pollutants degraded by the WRF were listed below in the Table 2.3.

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dyes</strong></td>
<td>Azure B; Congo red; Disperse Yellow 3; Orange II; Poly R; Reactive black 5; Reactive orange 96; Reactive violet 5</td>
</tr>
<tr>
<td><strong>Chlorinated aromatic compounds</strong></td>
<td>Chlorophenols [e.g. pentachlorophenols (PCP), trichlorophenols (TCP), and dichlorophenols (DCP)]; Chlorolignols; Polychlorinated biphenyls (PCBs); Dioxins; Chlorobenzenes</td>
</tr>
<tr>
<td><strong>Nitroaromatics</strong></td>
<td>2,4,6-Trinitrotoluene (TNT); 2,4-Dinitrotoluene; 2-Amino-4,6-dinitrotoluene; 1-Chloro-2,4-dinitrotoluene; 2,4-Dichloro-1-nitrotoluene; 1,3-Dinitrobenzene</td>
</tr>
<tr>
<td><strong>Pesticides</strong></td>
<td>Alachlor; Aldrin; Chlordane; 1,1,1-Trichloro-2,2-bis(4-chlorophenyl)ethane (DDT); Heptachlor; Lindane; Mirex; Atrazine</td>
</tr>
<tr>
<td><strong>Phenols</strong></td>
<td>Phenol; p-Cresol</td>
</tr>
<tr>
<td><strong>Polycyclic aromatic hydrocarbons</strong></td>
<td>Anthracene; 2-Methyl anthracene; 9-Methyl anthracene; Benzo[a]pyrene; Fluorene; Naphthalene; Acenaphthena; Acenaphthylene; Phenanthrene; Pyrene; Biphenylene</td>
</tr>
</tbody>
</table>

Sources: Knapp et al., 2001; and Reddy and Mathew, 2001.
Industrial textile dyes are manufactured and synthesized to be highly resistant to washing, chemical agents and environmental factors, such as the action of sunlight, water and microbial attack. A large portion of dyes, that is lost during the dyeing process, could remain intact, given the fact that both traditional physicochemical and biological wastewater treatments are unable to perform a proper degradation and decolourization for majority of the available dyes (Shaul et al. 1991; Gill et al. 2002). Reactive dyes have poor fixation to fabrics and dye concentrations up to 1,500 mg/L found in the liquor that is discharged into the sewers (Pierce 1994). About 90% of reactive dyes persist after being subjected to activated sludge treatment. Hence the widely used reactive dye in the Indian textile dye industries is one of the most recalcitrant to the conventional wastewater treatments.

The conventional activated sludge process which are widely used in many textile dye industries located in Tiruppur, Erode, Salem and Perundurai, Tamilnadu, India removes up to 80% of dyes in which 50% of it remains absorbed in the biomass, remaining 40% of the dyes only biomineralized hence producing high levels of sludge. Though the anaerobic microbes involved in the anaerobic process results in better decolourization efficiency, low sludge production and the production of methane as energy source, the production of toxic carcinogenic aromatic amines, resulting in recolourization when contact with the air and further aerobic process requirement screen them for the usage in the treatment process of the textile dye industries. Hence there comes the need for identifying the microorganisms capable for degrading the recalcitrant nature
and xenobiotic compounds of the textile dye effluents without causing any harm to the environment by its bye products. As the WRF due to their extracellular enzymatic action degrade the dye compounds and consume the dye compounds for their metabolic activities.

The role of WRF in the treatment of dye waste water has been extensively researched. WRF has proved to be a suitable organism for the treatment of textile dye. The fungal mycelia have an additional advantage over single cell organisms by solubilizing the insoluble substrates by producing extracellular enzymes. Due to an increased cell-to-surface ratio, fungi have a greater physical and enzymatic contact with the environment. The extracellular lignin modifying enzymes (LME) consisting of lignin peroxidase (LiP), manganese peroxidase (MnP) and laccase are key components of the lignin-degrading enzyme system of WRF. These enzymes are relatively non-specific and provide WRF the unique ability to degrade a broad array of environmental pollutants such as dioxins, polychlorinated biphenyls (PCBs), petroleum hydrocarbons, munitions wastes (such as trinitrotoluene), industrial dye effluents, herbicides and pesticides (Aust 1990; Pointing 2001; Reddy and Mathew 2001). The extra-cellular nature of the WRF enzyme is also advantageous in tolerating high concentration of the toxicants. Many genera of fungi have been employed for the dye decolourization either in living or dead form (Prachi Kaushik & Anushree Malik, 2009). Since the enzymes are extracellular, the substrate diffusion limitation into the cell, generally observed in bacteria is not encountered. WRF do not require preconditioning to particular pollutants, because enzyme secretion depends on
nutrient limitation, nitrogen or carbon, rather than presence of pollutant. The extracellular enzyme system also enables WRF to tolerate high concentrations of pollutants.

Dyes are removed by fungi through biosorption, biodegradation, bioaccumulation and enzymatic mineralization (Lignin peroxidase, Manganese peroxidase, Manganese independent peroxidase and Laccase) Wesenberg et al., 2002). Biosorption is defined as binding of solutes to the biomass by processes which do not involve metabolic energy or transport. Biodegradation is an energy dependent process and involves the breakdown of dye into various products through the action of various enzymes. Bioaccumulation is the accumulation of pollutants by actively growing cells by metabolism.

2.10 REPORTS BY RESEARCHERS

Many findings been evolved in the treatment of the textile dye effluent for the past two decades by their process involved, bioreactors used and the action of microbes. Following are the reports related to the findings for the decolourization and biodegradation of textile dye effluent,

Zhang et al (1998) studied continuous fluidized-bed bioreactor developed for the decolourization of cotton bleaching effluent with a wood rotting fungus. Different initial concentrations of effluent were tested with either glucose or starch as co-substrates. With this system, 75% to 80% colour removal was achieved with an initial A$_{400}$ of 4.7, using a 3 day-retention time. It showed high and stable decolourisation activity in long term continuous operation.
J. Swamy et al. (1999) evaluates the five species of WRF *Bjerkandera* sp. BOS55, *Trametes hirsuta*, *Phanerochaete chrysosporium*, *Pleurotus ostreatus* and *Trametes versicolor* for their ability to decolorize Amaranth, Remazol Black B, Remazol Orange, Remazol Brilliant Blue, Reactive Blue and Tropaeolin O in agar plates. *Bjerkandera sp. BOS55*, *Phanerochaete chrysosporium*, and *Trametes versicolor* displayed the greatest extent of decoloration. In static aqueous culture, the three cultures formed fungal mats which did not decolorize any dye beyond some mycelial sorption. When agitated at 200 rpm, the biomass grew as mycelial pellets. *Bjerkandera sp. BOS55* pellets decolorized only Amaranth, Remazol Black B, and Remazol Orange. *P. chrysosporium* and *T. versicolor* pellets were capable of decolorizing most dyes with decoloration by *T. versicolor* being several times more rapid. Batch cultures of *Bjerkandera sp. BOS55* and *P. chrysosporium* had a limited ability to decolorize repeated dye additions; however, *T. versicolor* rapidly decolorized repeated additions of the different dyes and dye mixtures without any visual sorption of any dye to the pellets.

Swamy and Ramsay (1999) investigated the potential of five cultures of WRF for their ability to decolorize Amaranth, Remazol Black B and Tropaeolin O in agar plates. According to their findings, *Bjerkandera sp. BOS55*, *Phanerochaeta chrysosporium* and *Trametes versicolor* showed the greatest extent of decolourization.
**Wong and Yu et al. (1999)** worked on some textile dyes which were not uniformly degraded by microbial attack in conventional aerobic treatment because of their unique and stable chemical structures. Both the researchers used three synthetic dyes anthraquinone, azo and indigo with typical chromophores. These were decolorized by a white-rot fungus *Trametes versicolor*.

**Zhang et al. (1999)** reported that the reactors systems used in dye decolourization by WRF included stirred tank reactors, a packed-bed bioreactor, airlift reactors, a rotating disc reactor and silicone membrane reactors, etc. In addition, they used the three different reactor configuration (continuous packed-bed bioreactor, fed batch fluidized-bed bioreactor and continuous fluidized-bed bioreactor) to design and test for decolourization of an azo dye, Orange II, with white rot fungus. It was found that the fed batch fluidized-bed bioreactor was particularly suitable for Orange II decolourization since it showed very high decolourization efficiency (over 97% color removal of 1000 mg/l Orange II in one day with immobilized fungal mycelium).

**Abadulla et al. (2000)** reported that *T. hirsuta* and a purified laccase from this organism was able to degrade triarylmethane, indigoid, azo, and anthraquinonic dyes. Immobilization of the *T. hirsuta* laccase on alumina enhanced the thermal stabilities of the enzyme and its tolerance against some enzyme inhibitors, such as halides, copper chelators, and dyeing additives.

**Fu and Viraraghavan (2001)** worked on decolourization of waste water by white rot fungi. During the last few decades there had been much focus on on
fungal decolourization of dye wastewater. Bioremediation by WRF is becoming a promising alternative to replace present treatment processes. Their research work included investigation of several fungi, alive or lifeless cells. They found that these had a potential for decolorizing textile dyes effluents and explained different processes.

Chagas and Durrant (2001) studied decolourization of azo dyes by *Phanerochaete chrysosporium* and *Pleurotus sajur-caju*. A lot of synthetic dyes used in industrial wastewater were opposed to degradation by trivial methods for treatments. They examined decolourization of four synthetic dyes using two white rot fungal cultures medium. *P. chrysosporium* mainly decolorized all the dyes under investigation, whereas *Pleurotus sajur-caju* entirely decolorized New Coccine, Orange G, Amaranth and 60% tartrazine. Neither fungus showed lignin peroxidase or veratryl alcohol oxides activities, indicating that those enzymes might not be involved in decolourization. β-glucosidase and Manganese-peroxidase might be concerned in decolourization of the dyes by *P. chrysosporium*, whereas in *Pleurotus sajur-caju* a laccase was active towards Odianisidine and glucose 1-oxidase might participate in the whole process.

Driessel and Christov (2001) studied decolourization of dye based effluents in a rotating biological contactor (RBC) reactor using *Coriolus versicolor* and *Rhizomucor pusillus* strain RM7, a mucoralean fungus. The results showed that decolourization by the selected two fungi was in a straight line proportional to original color intensities. Moreover, it was noted that the
level of decolourization was not badly affected by intensity of color, except at the minimum level examined. In addition to this 53% to 73% decolourization might be obtained by making use of a hydraulic retention time (HRT) of almost one day. 55% of AOX were removed with *R. pusillus*, and 40% by *C. versicolor*. Treatment with these fungal cultures *R. pusillus* and *C. versicolor* left the effluent in essence non-hazardous. Glucose incorporation into decolourization media stimulated color reduction by *C. versicolor* and remained unaffected with *R. pusillus*. Ligninases enzymes (laccase and manganese peroxidase) were only found in effluent treated by *C. versicolor*. It also shows that decolorizing mechanisms are certainly between the white rot fungi. WRF showed adsorption + biodegradation while the mucoralean fungus showed adsorption only. This feature is needed to be examined in more detail to confirm the manners responsible for the decolourization process.

**Tim Robinson et al. (2001)** review the current available technologies and suggest an effective, cheaper alternative for dye removal and decolourisation applicable on large scale. Studied the various chemical and biological treatment techniques and presented the advantages and disadvantages of them and suggesting that the agriculture residues can be used for the adsorption of the dye wastewater and further treatment with the fungi for the saturation and then leaving for two weeks for the solid state fermentation to be carried over in increasing the nutrient value where the fermented mass can then be recycled, utilised as fertiliser or soil conditioner.
S. Sen et al (2002) investigated anaerobic treatability of a real cotton textile wastewater in a FBR (FBR) with pumice as the support material. The effect of operational conditions such as organic loading rate (OLR), hydraulic retention time (HRT), influent glucose concentration as the co-substrate, etc. was investigated to achieve the maximum color removal efficiency in the reactor. Results indicated that anaerobic treatment of textile wastewater studied was possible with the supplementation of an external carbon source in the form of glucose (about 2 g/l). The corresponding maximum COD, BOD5 and Color removals were found to be around 82%, 94% and 59%, respectively, for HRT of around 24 h and OLR of 3 kg COD/m3/d. Further increase in external carbon source added to real textile wastewater did not improve the colour removal efficiency of the anaerobic FBR reactor.

Sangyong Kim et al. (2002) studied performance of pilot scale combined process of fluidized biofilm process, chemical coagulation and electrochemical oxidation for textile wastewater treatment. Two species of microbes, Aeromonas salmonicida and Pseudomonas Vesicularis which can degrade textile wastewater pollutants efficiently were isolated and applied to the system with supporting media in the fluidized biofilm process. COD and colour removals of 95.4% and 98.5% were also achieved by the overall combined process of fluidized biofilm process, chemical coagulation and electrochemical oxidation. And the improvements of 13.0% COD removal and 19.7% colour removal was finally achieved by using support media at the overall combined process.
Faisal Ibney Hai et al. (2002) studied the factors governing performance of continuous fungal reactor during non-sterile operation in a membrane bioreactor treating textile wastewater and achieved 93% colour removal during non-sterile operation at an HRT of 1 d. Long-term observation of the performance of MBRs under different HRT and feeding mode as well as batch tests with pure fungus culture and reactor-sludge enabled identification of the reasons for the incomplete removal.

U. Welander et al. (2002) studied the decolourization of textile wastewater by conducting the batch and continuous reactors using white rot fungi. Natural luffa sponge and birch wood are the carrier materials used in the experiments and the white rot fungi, T. versicolor, P. Ostreatus, P. sajor-caju, P. Chrysosporium and P. Flabellatus were used for the evaluation. T. versicolor was shown to be able to decolorize Reactive Red 2 as well as Reactive Blue 4 when natural luffa sponge was used as carrier material and no measurable improvement in decolourization of the dye was found when the glucose based medium was used in comparison to the medium based on that the fungus is using the wood as carbon source.

Dirk Wesenberg et al. (2003) reviewed about the various White-rot fungi and their enzymes for the treatment of industrial dye effluents and reported that the Lignin Modifying Enzymes (LME) like laccase, Mn peroxidase and lignin peroxidase plays a vital role in the treatment of industrial effluents particularly dye containing effluents and summarized that the bio catalysis and stability
characteristics of WRF enzymes needs to get transformed into reliable and robust waste treatment processes of the bioreactor scale up for the industrial applications.

**Faisal Ibney Hai et al. (2003)** reported the performance of a bench-scale submerged microfiltration bioreactor using the white-rot fungus *Coriolus versicolor* (NBRC 9791) for treatment of textile dye wastewater. Stable decolouration activity (approx. 98%) and TOC removal (>95%) was achieved using the entire system (fungi+membrane), while the contribution of the fungi culture alone to color and TOC removal.

**Martin et al. (2003)** screened several fungi for degradation of syringol derivatives of azo dyes possessing either carboxylic or sulphonic group. *T. Versicolor* showed the best biodegradation performance and its potential was confirmed by the degradation of differently substituted fungal bioaccessible dyes. Biodegradation assays using mixtures of these bioaccessible dyes were performed to evaluate the possibility of a fungal wastewater treatment for textile industries.

**S. Padmavathy et al. (2003)** experimented for the aerobic decolourization of reactive azo dyes in presence of various co substrates using bacteria consortia showed good efficiency with the whey waste as co substrate achieving 95% of decolourization.
Sangyong Kim et al. (2003) studied and showed the effectiveness of biological pretreatment involving appropriate microorganisms and suitable support media in a combined process. The combined process consists of biological pretreatment, chemical coagulation and electrochemical oxidation. COD and Colour were reduced by 95.4% and 98.5% by the combined process, respectively. Results showed that the use of selected microorganisms and support media is a good method to enhance process performance in the treatment of wastewater.

Delia Teresa Sponza et al. (2005) conducted experiments using a lab-scale upflow anaerobic sludge blanket (UASB) reactor at different hydraulic retention times (HRT) in order to obtain the substrate removal kinetic of the reactor through decolourization of dyes by applying Monod, Contois, Grau second order, modified Stover-Kincannon, and first order kinetic models. The experimental data obtained from the steady-state conditions showed that Grau second order, modified Stover-Kincannon and Contois substrate removal kinetic models were suitable than the other applied models for predicting the performance of lab-scale UASB reactor treating the textile wastewater.

Kapdan et al. (2005) have done the kinetic analysis of decolourization and COD removal from synthetic textile wastewater in an anaerobic packed column reactor. 90% of decolourization was obtained for dyestuff loading rates up to 0.15 g/ (l day). COD removal efficiency was obtained between 5 and 35% for the applied loads. Modified Stover–Kincannon model was applied to the
experimental data. Umax, and saturation constant value, KB, were determined as
Umax = 0.47 g/ (l day) and KB = 0.43 g/ (l day) for dye and as Umax = 12.99 g
COD/ (l day), KB = 37.69 g COD/ (l day) for COD removal showed satisfactory
results between observed and predicted concentrations both for dyestuff and
COD removals.

**Jane-Yii Wu et al. (2005)** experimented the FBR with an immobilized
cell beads system achieving a colour removal efficiency of 90% at initial dye
concentration < 2200 mg L\(^{-1}\) under a continuous-flow condition.

**Juan Wu et al. (2005)** investigated five WRF in degrading the lignin to
treat wastewater from pulp and paper mill using porous plastic rings in batch
reactor. Over 71% of lignin and 48% of COD were removed from the
wastewater medium. Three WRF P.Chrysoporium, P.Ostreatus and S22 showed
high capacity of lignin degradation even at strong alkaline condition.

**Palmieri et al. (2005)** investigated decolorization of the recalcitrant dye
Remazol Brilliant Blue R by the fungus basidiomycete *Pleurotus ostreatus*.
According to them, *P. ostreatus* is able to decolorize RBBR on agar plate. When
grow in liquid media supplemented with veratryl alcohol, the fungus completely
decolorizes RBBR in 3 days. *P. ostreatus* produces among other enzymes,
laccases, veratryl alcohol oxidase and dye-decolorizing peroxidase but only
laccases seemed to be responsible of RBBR transformation.
M. Asgher et al. (2006) experimented with four white-rot fungi isolated in Pakistan for decolourization of widely used reactive textile dyestuffs. Phanerochaete chrysosporium, Coriolus versicolor, Ganoderma lucidum and Pleurotus ostreatus were grown in defined nutrient media for decolourization of Drimarene Orange K-GL, Remazol Brilliant Yellow 3GL, Procion BluePX-5R and Cibacron Blue P-3RGR for 10 days in shake flasks. It was observed that P. chrysosporium and C. versicolor could effectively decolorize Remazol Brilliant Yellow 3GL, Procion BluePX-5R and Cibacron Blue P-3RGR. Drimarene Orange K-GL was completely decolorized (0.2 g/l after 8 days) only by P. chrysosporium, followed by P. ostreatus (0.17 g/l after 10 days). P. ostreatus also showed good decolourization efficiencies (0.19–0.2 g/l) on all dyes except Remazol Brilliant Yellow (0.07 g/l after 10 days). G. lucidum did not decolorize any of the dyestuffs to an appreciable extent except Remazol Brilliant Yellow (0.2 g/l after 8 days).

S. Sandhya et al. (2006) studied the treatment of textile wastewater in an upflow anaerobic fixed bed (UAFB) reactor. COD and colour were reduced to 84.80%, and 90% for textile wastewater. Biokinetic models like Monod model, second-order and Stover–Kincannon model were applied for the UAFB reactor. Second-order model and Stover–Kincannon model gave higher correlation coefficients of 99%.

U. Welander et al. (2006) studied the decolourization of the textile dyes Reactive red 2 and Reactive blue 4 using Bjerkandera sp. Strain BOL 13 fungal
in a continuous rotating biological contactor reactor by varying the concentrations of the two dye mixtures and achieved efficient decolourization.

**D.S. Arora et al. (2007)** evaluated the potential of WRF for decolourization of industrial dyes. Study reflects the inherent potential of white-rot fungi in bio management of industrial dyes. The lesser explored organisms *D. squalens* and *I. flavus* could emerge as alternative, time and cost effective bio cleaning systems thus supporting their potential to be exploited for designing the novel biodegradation and bioremediation processes for coloured industrial effluents.

**Zhao and Hardin (2007)** employed a white rot fungus *Pleurotus ostreatus* for degradation of two commercially used disperse azo dyes, Disperse Orange 3 and Disperse Yellow 3. UV-visible spectrophotometric method and high performance liquid chromatography (HPLC) for decolourization and products from fungal degradation of these azo dyes in liquid medium were determined. Their decolourization studies showed, that both azo dyes were removed by more than 50% in 5 days and HPLC analysis determined several degradation products. These results suggest that P. ostreatus has potential in color removal from textile wastewater containing disperse.

**Murugesan et al. (2007)** applied response surface methodology (RSM) for the decolourization of the azo dye reactive black 5 (RB-5) using purified laccase from a White rot fungus *Pleurotus sajur-caju*. According to their observation, the optimum concentrations of dye, enzyme, HBT, and time were
found to be 62.5 mg/L, 2.5 U/mL, 1.5 mM and 36 h, respectively, for maximum
decolourization of RB-5 of 84.4%. A quadratic model was obtained for dye
decolourization through this design. The experimental values were in good
agreement with predicted values and the model was highly significant, the
correlation coefficient being 0.999. Increased decolourization was observed with
increase in enzyme concentration.

**Youssef Zeroual et al. (2007)** experimented with Geotrichum sp. fungal
strain ability to decolorize azo dyes enzymatically, the biomass of Geotrichum
sp. was immobilized in calcium alginate and polyacrylamide gels and used for
the decolourization of tested azo dyes in FBRand concluded the highest specific
decolourization rate was obtained when the fungal biomass was entrapped in
calcium alginate beads.

**S.M. Borghei et al. (2008)** have done the process kinetics of a lab-scale
upflow aerobic immobilized biomass (UAIB) reactor using simulated sugar-
manufacturing wastewater. The UAIB reactor was tested under different organic
loads and different hydraulic retention times (HRT) and the substrate loading
removal rate was compared with prediction of Stover–Kincannon model,
second-order model and the first order substrate removal model. Stover–
Kincannon model and Grau second order model gave high correlation
coefficients of 99.7% and 99.4%, respectively.

**S. Sandhya et al. (2008)** determined the kinetic constants of
microaerophilic–aerobic hybrid reactor in treating the textile wastewater. COD
and color were reduced to 82–94% and 99% respectively for textile wastewater. Biokinetic models such as Monod model, second-order and Stover–Kincannon model were applied for the hybrid reactor. Second-order model and Stover–Kincannon model gave higher correlation coefficients. Second-order and Stover–Kincannon models were best fitted to the hybrid column reactor.

Youssef Touhami et al. (2008) evaluated the performance of a combined aerobic system using continuous stirred tank reactor (CSTR) and fixed film bioreactor (FFB) for treating the textile wastewater. He presented with a higher degradative capacity of 97.5% and a higher colour removal efficiency of 97.3%, obtained with a long HRT of 4 days and low wastewater loading rate (WLR) of 0.296 g l−1 d−1. The performance of the system was evaluated that the increase of WLR and the decrease of HRT diminished the performances of the system in terms of decolourization and COD removal.

Ulson de Souza et al. (2008) investigated the biodegradation of textile industry effluents, in an aerobic FBR. Seven different effluents were tested with the aim of determining the degradability of different textile industry effluent streams using an aerobic process in a fluidized reactor with adhered biomass. Reduction efficiencies for filtered COD for the different effluents fed to the reactor were 80 and 72% for the stabilization tank, 60 and 28% for the holding tank stream and 74% for the neutralization tank stream. Study reveals that the application of aerobic processes with bio films is an excellent alternative for reducing COD in industrial textile effluents, without the use of chemicals
compounds, which are utilized in the traditional effluent treatment processes, making this biofilm technology “environmentally friendly”.

Anushree Malik et al. (2009) reviewed the recent advances and future potential of fungal decolourization. Review suggested that Fungus can be employed as a vital biological tool for developing decentralized wastewater treatment systems for decolourization of dye effluents through biosorption or biodegradation. Such systems could be particularly useful for small-scale textile or dyeing units because most of the fungal strains can be supported on locally available and low-cost growth substrates. Further, handling and separation of biomass from treated effluents is also easier as compared to bacterial biomass.

S.V. Srinivasan et al. (2009) investigated a systematic optimization of the important variables influencing the decolourization of Reactive Orange-16 (RO-16) and Reactive Red-35 (RR-35) dyes by the white-rot fungus Trametes versicolor. The effect of concentrations of dye, glucose and ammonium chloride on decolourization was studied and optimized using Response Surface Methodology (RSM). Maximum decolourization of 94.5% and 90.7% for RO-16 and RR-35 was obtained.

S. Andleeb et al (2010) reported that the FBR with sand as immobilizing support (FBR1) for Aspergillus niger fungal species showed overall better performance as compared to FBR with sodium alginate as immobilizing support (FBR2) for Aspergillus niger. The average overall Colour, BOD and COD removal in the FBR1 system were up to 78.29, 70.81 and 83.07% respectively,
with 50 ppm initial dye concentration of Drimarene Blue dye and HRT of 24 h. While 72.19%, 86.63% and 74.74% removal of Colour, BOD and COD were observed, respectively, in FBR2 with the same conditions. Reductions in BOD and COD levels along with color removal proved that decolourization and biodegradation occurred simultaneously.

**P. Saranraj et al. (2010)** reported that economical and eco-friendly techniques using fungi can be applied for fine tuning of waste water treatment. Biotreatment offers easy, cheaper and effective alternative for colour removal of textile dyes. The study concluded that the fungal isolates like *Aspergillus niger*, *Aspergillus flavus*, *Aspergillus fumigatus*, *Fusarium oxysporum*, *Penicillium chrysogenum*, *Mucor* sp. and *Trichoderma viride* were used as a good microbial source for waste water treatment.

**Hye Ok Park et al. (2011)** evaluated the effectiveness of a combined process of fungal moving-bed biofilm reactor and chemical coagulation for dyeing wastewater treatment. The contribution of biological treatment by fungal MBBRs to the overall system in COD and color removal efficiency was up to 79% and 54%, respectively. In overall, 95.7-96.6% of COD and 67.5-73.4% of color were removed by the combined MBBRs and additional chemical coagulation process. The combined process of MBBRs and chemical coagulation was highly efficient in textile dyeing wastewater treatment.

**Moutaouakkil et al. (2011)** proved that high efficiency decolourization of water contaminated by the anthraquinone dye CB using immobilized
Coprinus cinereus in a FBR is feasible, more than 95% of the coloration was removed between the 4th and the 7th day, at which time the fungal biomass began to grow intensively.

Sérgio L. et al. (2011) proved the biotechnological potential of Brazilian basidiomycetes, able to decolourize the simulated textile effluent containing sodium chloride and pH 8.0. The strains of P. ostreatus, P. cinerea and T. villosa stood out as promising for the biodegradation of textile dye in alkali-saline effluent.

Włodzimierz Sokół et al. (2011) investigated the aerobic degradation of high-strength industrial (refinery) waste- waters in the inverse fluidized bed biological reactor, in which polypropylene particles of density 910 kg/m$^3$ were fluidized by an upward flow of gas through a bed. The largest COD reduction, namely, from 54,840 to 2190 mg/l, i.e. a 96% COD decrease was achieved.

R.Rajendran et al. (2011) reported that the consortium of microbes with its wide spectral enzymatic system with or without substrate specificity helps in reducing any number of dyes containing aromatic rings present in the effluent. Only such treatment should be employed in a common effluent treatment plant as the dyeing units deal with more number of dyes daily.

Lamia Ayed et al. (2011) suggested that that the decolourisation rate and chemical oxygen demand (COD) were 86.72% and 75.06%, respectively was achieved by the bacterial consortium using aerobic system the continuous
stirred bed reactor and he added to the conclusion part of his research that the mixture design of the microbes will be most preferred for the decolourization process.

Simone Papadia et al. (2011) identified the most effective bioreactor system for the secondary treatment of a wastewater resulting from a textile industry, four pilot units characterized by a different configuration and fluid dynamics namely Bioflotation, Fixed Bed Biofilm Reactor (FBBR), Flow-jet aeration and Standard aerobic sludge reactors were operated in parallel, inoculated with the same microbial consortium and fed with identical streams of wastewater discharged from wet textile processes of the industry. The results demonstrated that the air supply system greatly influenced the treatment efficiency which reached the highest value in the reduction of COD, Total Carbon and Surfactants in the case of Bioflotation and FBBR technology.

V.Malini Devi et al. (2012) suggested that the laccase enzyme from the fungus Pleurotus ostreatus possesses a significant dye degradation capacity and further can be applied in bioremediation of toxic industrial dyes.

Yongjun Zhang et al. (2012) designed and studied about a novel plate bioreactor for the elimination of carbamazepine (CBZ) a recalcitrant compounds widely concerned in pharmaceutical, with the help of white rot fungus Phanerochaete chrysosporium grown on polyether foam under non-sterile conditions. The bioreactor was operated in both sequence batch and continuous modes. It was found that the sufficient supply with nutrients is crucial for an
effective elimination of CBZ. High elimination of CBZ (60–80%) was achieved. The effective elimination was stable in a continuous operation for a long term (around 100 days).