CHAPTER - II

LITERATURE REVIEW
CHAPTER 2

LITERATURE REVIEW

2.1 PERCEPTION OF COLOUR: -

Perception of colour is the ability of a person to detect some wavelengths of electromagnetic (light) radiation differently from other wavelengths. The relative intensities of various wavelengths of visible light observed by the eye are translated by the mind of the observer resulting in the perception of color.

Day light is a mixture of different wavelengths of radiation to which we respond and some to which we cannot respond for e.g. the infrared and ultra-violet rays. We respond to wavelengths between about 400-700 nm. Radiation falling below 400 nm is ultraviolet radiation, and that falling above 700 nm is infrared radiation; both are unseen by the human eye [57]. When an object absorbs some of the radiations we see the waves that are left over and the object appears colored.

If white light (sunlight) is allowed to pass through a prism it spreads out and we can see that it is composed of different colors. Each color corresponds to a different wavelength. If pure light of a given wavelength is observed, it will have a color corresponding to that wavelength. Sunlight, incandescent light, and fluorescent light are different light sources of various wavelengths. Fluorescent lights generally contain large amounts of shorter, blue wavelengths, while incandescent tungsten lights contain a large component of longer, red wavelengths.

The net color seen by the observer is dependent on integration of three factors: (1) the nature of the light source, (2) the light absorption properties of the object observed, and (3) the response of the eye to the light reflected from the object. Differences in intensity and wavelength distribution between light sources have a profound effect on the color of a dyed textile, since the textile can absorb and reflect only that light available to it from the source. When a dyed fabric appears different in color or shade under two different light sources, the phenomenon is referred to as "flare." When two fabrics dyed
with different dyes or dye combinations match under one light source but not under another, the effect is called "metamerism."

When light from a source strikes a dyed textile surface, different portions of the light of various wavelengths are absorbed by the dye, depending on the structure and light absorption characteristics of the dye. Light not absorbed by the dye on the textile is reflected from the surface as diffused light, and the observer sees the colors shown in Table 2.1. We perceive the complementary color because the light, which reaches our eye, is missing the wavelengths, which have been absorbed. The color seen is a composite of all the wavelengths reflected from the fabric. If significant direct reflectance of light from the fabric occurs, the fabric exhibits a degree of a gloss. If the fabric absorbs little or no light throughout the visible range and the majority of light is reflected, the fabric appears white. If the fabric absorbs all of the light striking it, the fabric is black. If uniform light absorption and reflectance across the visible wavelengths occurs at some intermediate level, the fabric will be a shade of gray.

Thus, color is fundamentally dependent on the removal of light of particular wavelengths from the spectrum by the dye concerned. Most dyes absorb different wavelengths.

<table>
<thead>
<tr>
<th>Wavelength of light, nm</th>
<th>Color</th>
<th>Complementary color</th>
</tr>
</thead>
<tbody>
<tr>
<td>400-430</td>
<td>Violet</td>
<td>Green-yellow</td>
</tr>
<tr>
<td>430-480</td>
<td>Blue</td>
<td>Yellow</td>
</tr>
<tr>
<td>480-490</td>
<td>Green-Blue</td>
<td>Orange</td>
</tr>
<tr>
<td>490-510</td>
<td>Blue-Green</td>
<td>Red</td>
</tr>
<tr>
<td>510-530</td>
<td>Green</td>
<td>Purple</td>
</tr>
<tr>
<td>530-570</td>
<td>Yellow-Green</td>
<td>Violet</td>
</tr>
<tr>
<td>570-580</td>
<td>Yellow</td>
<td>Blue</td>
</tr>
<tr>
<td>580-600</td>
<td>Orange</td>
<td>Green-Blue</td>
</tr>
<tr>
<td>600-680</td>
<td>Red</td>
<td>Blue-Green</td>
</tr>
</tbody>
</table>

The color that we see is referred to as the complimentary color of the color that is removed. For instance, if the red rays are removed from white light the color we see is blue-green. Blue-green is complementary to red and red is complementary to blue-green.
2.2 **DYE COMPOUNDS:**

A dye or a dyestuff is usually a colored, ionizing, aromatic organic compound or mixture that may be used for imparting colour to a substrate such as cloth, paper, plastic or leather in a reasonably permanent fashion [119]. It is fundamentally based on the structure of benzene. It is a chemical and like all other chemicals may be toxic, carcinogenic, mutagenic, or harmful to health in some way or the other.

In general, dyes are colored molecules soluble or dispersible in water or solvent media, which can penetrate the fiber on coloration, whereas pigments are not dispersible and must be mechanically entrapped in or locked to the fiber by a binding resin. A series of color- less dyes exist which are called "fluorescent brighteners." These dyes absorb little light in the visible region, but absorb radiation at unseen ultraviolet wavelengths and then emit this radiation at long blue wave- lengths to provide an optical bleaching effect on fabrics [57]. Fluorescent dyes combine fluorescence with visible light absorption characteristics to give extremely bright colors, since unseen ultraviolet light is also being made visible to the eye.

Dyes are made up of two parts: chromophores and auxochromes.

2.2.1 **Chromophores:**

Colour usually appears in an organic compound if it contains certain unsaturated groups called chromophores (Greek chroma-colour, and phoros, bearing). Chromophores are atomic configurations composed of atoms joined in a sequence of alternating single and double bonds [119,53]. The ability of a compound to absorb light depends on the presence of these structural features.

Some Typical Chromophores are: -

1. \(-N=O\) Nitroso  
2. \(>C=S\) thiocarbonyl  
3. \(\rightarrow C=O\) Carbonyl  
4. \(\rightarrow C=\) Ethylenic  
5. \(\rightarrow C=\) Ethylenic  
6. \(\rightarrow C=\) Ethylenic  
7. \(\rightarrow C=\) Ethylenic

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Chromophores are of two types:

(a) Independent chromophores:- These single chromophores are independently sufficient to impart colour to the compound. Examples of such chromophores are:-

(1) –N = O, (2) –NO₂, (3) –N = N, (4) –N = N-NH,
(5) –N=N→O,

(b) Dependent Chromophores: - These require more than one chromophore to impart colour. Examples of such chromophores are given below.

(1) >C = O, (2) >C = C<

For example, acetone, containing one carbonyl group, is colourless while biacetyl, containing two carboxyl groups, is yellow. A single C=C group does not produce colour in the compound but if a number of them are present in conjugation, the colour usually appears. For example Ethylene, CH₂ = CH₂ is colorless while CH₃(CH₂)₆CH₃ is yellow.

Another example is that of Diphenylpolyenes: - Ph (CH=CH)ₙ Ph.
When \( n \) is 1 or 2, the compound is colorless. However, when \( n \) is 3, the compound becomes yellow and when \( n \) is further increased, the colour gets deepened, i.e. when \( n \) is 5, the colour is orange, when \( n \) is 7, the colour is copper-bronze and when \( n \) is 11, the colour is violet-black.

The shade of the colour is also influenced by the proximity of the chromophores. If other groups separate these, the compound becomes colorless. For example

\[
\begin{align*}
(1) & & \text{CH}_3-C-C-\text{CH}_3 & & \text{yellow in colour} \\
(2) & & \text{CH}_3-C-\text{CH}_2-\text{CH}_2-C-\text{CH}_3 & & \text{a colourless compound}
\end{align*}
\]

### 2.2.2 Auxochromes:

These compounds containing chromophoric group are called “chromogens”. A chromogen may be colored but it does not represent a dye. The presence of certain groups in a chromogen lead to a deepening of the color although these groups are not chromophores themselves and do not impart colour to the compound when present without the chromophore. These groups are called auxochromes (Greek auxein-to increase and chroma -colour).

#### Table 2.2

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name</th>
<th>Group</th>
<th>Name</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Amino</td>
<td>−NH₂</td>
<td>Chloro</td>
<td>−Cl</td>
</tr>
<tr>
<td>2.</td>
<td>Methylamino</td>
<td>−NHCH₃</td>
<td>Methyl</td>
<td>−CH₃</td>
</tr>
<tr>
<td>3.</td>
<td>Dimethylamino</td>
<td>−N(CH₃)₂</td>
<td>Methoxy</td>
<td>−OCH₃</td>
</tr>
<tr>
<td>4.</td>
<td>Sulphonic acid</td>
<td>−SO₂H</td>
<td>Cyano</td>
<td>−CN</td>
</tr>
<tr>
<td>5.</td>
<td>Hydroxy</td>
<td>−OH</td>
<td>Acetyl</td>
<td>−COCH₃</td>
</tr>
<tr>
<td>6.</td>
<td>Carboxylic acid</td>
<td>−COOH</td>
<td>Acetamido</td>
<td>−CONH₂</td>
</tr>
</tbody>
</table>
2.2.3 Interactions:

Dyeing is a process, in which certain interactional forces help transfer colour to the substances being dyed.

(a) Ionic interactions:

These arise from ionic sites for opposite charge in the fiber and the dye molecules. For example, the dyeing of wool with acid dyes is mainly due to the formation of salt type chemical links between dye anions and cationic groups in that fiber.

(b) Hydrogen bonds:

These interactions are weak and are formed by sharing a lone pair of electrons of nitrogen, oxygen or fluorine in a molecule with covalently bonded hydrogen atom. The hydrogen bonds are involved in dyeing of wool, silk, and man-made fibers. Several hydrogen bonds forming between the dye molecule and the fiber structure at a time may be sufficiently strong to hold the dye molecule to the fiber structure.

(c) Van der Waal’s interactions:

These interactions are weak and arise due to interactions between molecules close to each other. Van der Waal’s interactions become strong when dye and fiber molecules belong to the similar groups e.g. alkyl, aryl in polyester. When the total effect of such interactions becomes greater, the dye attaches to the fiber.

(d) Covalent bonds:

These bonds are formed between dye and fiber molecules due to the reaction between reactive dye and groups such as - OH. These dyes are fast to washing.

2.2.4 Nomenclature of dyes:

The dye manufacturing industry is synthesizing as many as 3600 dyes for commercial use presently. Various systems of nomenclature are used to name these dyes.
Individual manufacturers coin commercial names of dyes and these usually consist of three or four parts. The trademark name of the class comes first and is followed by words, letters or numbers. These describe the shade and other characteristics like strength, physical form etc. The alphabetical letters following the trade name may refer to the shade of the dye e.g.

\[ Y \text{ or } G = \text{Yellow (gelb)} \]
\[ R = \text{Red (rot)} \]
\[ B = \text{Blue} \]
\[ O = \text{Orange} \]

Thus, G stands for German word gelb (yellow), R for German word rot (red) and B for German word blau (blue). For example Astrazon Yellow 3G is a basic dye having considerable yellow tone. Similarly, Acridine Orange R and Astrazone Orange R are basic dyes with reddish tone. Rhodamine B (basic dye) and Remazol Red B (reactive dye) are dyes with bluish tone.

The numbers with the above letters indicate the greater intensity of the tone. For example methyl violet 6B is a very deep purple (close to bluish) tone, similarly alkali fast Green 3B is a green acid dye having considerable bluish tone.

Sometimes letters are used to represent the class of the dye. For example, in Alizarin Blue D, the letter ‘D’ indicates that dye is a direct dye for cotton.

Sometimes letters are also used to represent the property of a dye. For example, the letter ‘F’ is used to indicate that the dye is fast to certain agencies such as light, washing etc. The letter ‘L’ appears in the name of the dye, indicating that this dye produces a shade on a fiber and is fast to light. Examples having this letter are Basacryl Yellow 5 GL, Basacryl Yellow 5 RL and Basacryl Violet RL, disperse dyes for polyester fibers such as Foron Grey S-4 GL and Foron Scarlet E-2 GFL; direct dyes such as Kiton Fast Yellow 2 GL, Chlorantine Fast Blue 10 GL and Benzo Fast Red 8 BL.

In the case of reactive dyes, belonging to the chlorotriazine class, reactivity has been found to depend upon the number of chlorine atoms present in the molecule. If the
molecule of a dye has two chlorine atoms, they are highly reactive and can be used in cold condition. Hence, they are termed as cold brand (cold dying) reactive dyes. Thus, their names have the letter ‘C’ e.g. Premactive C and Goldazol C.

There are also dyes, which have only one chlorine atom. These dyes are less reactive and therefore, the dye solutions have to be heated for their greater reactivity. Thus, they are termed as hot brand (hot dyeing) reactive dyes and hence their names have the letter ‘H’ e.g. Procion H and Premactive H.

The letter I generally indicates that the dye belongs to a special class of vat dyes, the solubilized vat dyes. They are subdivided into various groups such as I\textsubscript{k}, I\textsubscript{n}, I\textsubscript{e} depending on the condition of temperature used. For example, I\textsubscript{k} group of vat dyes is employed in the cold condition, i.e. at 20-30°C. Further, I\textsubscript{n} and I\textsubscript{e} group of vat dyes are employed under conditions of temperature 30-40°C and 50-60°C respectively.

The letters ‘N’ and ‘K’ indicate that it is vat dye which can be applied to cellulose fibers by a particular method of dyeing involving normal and cold temperature conditions respectively e.g. Indanthrene Golden Yellow GK, Indanthrene Brilliant Orange RK, Algol Yellow GCN, Caledon Jade green BN.

The intensity of tone, tone of the colour and condition of temperature of dyeing are indicated as in Indanthrene Yellow GK, Indanthrene Yellow 4 GK, Indanthrene Yellow 5 GK and Indanthrene Yellow 7 GK (In this case, yellowish tone tends to increase).

The advantage of using commercial names is that they are short, symbolic and simple even for a layman in the trade. Chemical nomenclature may often lead to confusion.

However, the main drawback of this system of nomenclature is that the same dye has been given various names by different manufacturers, e.g. rose-red dye is named pararosaniline, magneta or fuchsine. In order to overcome this difficulty, a colour index has been compiled.
2.2.5 Colour Index naming of dyes:

The best method for nomenclature of dyes is the Colour Index, [7] a publication sponsored by the Society of Dyers and Colorists (England) and the American Association of Textile Chemists and Colorists.

Dyes classified by this scheme are assigned standard designations according to dye class, color, and overall constitution. Each dye is given two reference numbers, one relating to its class with respect to dyeing method (e.g. C.I. Acid Blue 141, Vat Green 17, Disperse Red 17 and Vat Blue 4). The other reference is given to its chemical description in five digits (e.g. C I. 69800 for indanthrone i.e. Vat Blue 4). All the commercial names under which a dye is sold (over 37 for Indanthrone) are listed in the colour index.

Dye makers sell a majority of their products under a trade name, color index name/number. Color index name/number has the additional advantage of allowing dyestuff equivalent to be looked up. An equivalent is the same dye made by two or more makers. Such dyes have the same CI (color index) name/number within a given application group.

2.2.6 Dye classification:

The major dye classes are given in Table 2.3. Dyes may be classified in a number of ways, including color, intended use, trade name, chemical constitution, and basis of application. Of these classification methods, chemical constitution and basis of application have been most widely used. Chemical constitution indicates the major chromophores present in the dye but does not indicate more than such structural aspects of the dye.
### Table 2.3

**Major dye classes [57]**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Dyes containing anionic functional groups</th>
<th>Dyes containing cationic functional groups</th>
<th>Dyes requiring chemical reaction before application</th>
<th>Special colorant classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Acid dyes</td>
<td>Basic dyes</td>
<td>Vat dyes</td>
<td>Disperse dyes</td>
</tr>
<tr>
<td>2.</td>
<td>Direct dyes</td>
<td></td>
<td>Azoic dyes</td>
<td>Solvent dyes</td>
</tr>
<tr>
<td>3.</td>
<td>Mordant dyes</td>
<td></td>
<td>Sulfur dyes</td>
<td>Pigments</td>
</tr>
<tr>
<td>4.</td>
<td>Reactive dyes</td>
<td></td>
<td></td>
<td>Natural dyes</td>
</tr>
</tbody>
</table>

The terms acidic / basic / neutral used in dye classification bear no relationship to the pH of a solution of a particular dye.

### 2.2.7 Application of dyes:

Various dyeing or printing techniques can be used to apply color to textiles. They may be applied at a number of points within the textile construction process. In order to dye the substrate it is immersed in the dye bath for a specified time at optimum temperature. For getting level dyeing, stirring arrangement is used. Level dyeing indicates the uniformity of the dye on the fiber, yarn or fabric [57]. This depends on the nature of the dye, the absorptive power of the substrate and the conditions of dyeing.
<table>
<thead>
<tr>
<th>Type of Fiber</th>
<th>Acrylic</th>
<th>Cotton</th>
<th>Rayon</th>
<th>Polyester</th>
<th>Acetate</th>
<th>Wool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Dye</td>
<td>Acid</td>
<td>Aniline</td>
<td>Basic</td>
<td>(Cationic)</td>
<td>Developed</td>
<td>Dye blends</td>
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<tr>
<td></td>
<td>Dye</td>
<td>Dye</td>
<td>Disperse</td>
<td>Fiber-reactive</td>
<td>Fluorescent</td>
<td>Indigo</td>
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<td></td>
<td>Pigments</td>
<td></td>
<td></td>
<td></td>
<td>Sulfur</td>
<td>Vats</td>
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<td></td>
<td>Pigments</td>
<td></td>
<td></td>
<td></td>
<td>Natural</td>
<td>Oxidation</td>
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<tr>
<td></td>
<td>Pigments</td>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>Mordant</td>
</tr>
</tbody>
</table>

TABLE 2.4: Types & amounts of dyes used in textile industry [108].

<table>
<thead>
<tr>
<th>AMOUNT USED %</th>
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<th>AMOUNT USED %</th>
<th>AMOUNT USED %</th>
<th>AMOUNT USED %</th>
<th>AMOUNT USED %</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3</td>
<td>6</td>
<td>15</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>X</td>
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</tbody>
</table>
Fiber or stock dyeing involves dyeing of loose fibers or fiber top or sliver before yarn formation to ensure uniform coloration throughout the fiber. This technique is referred to as “solution” or “dope dyeing”. Yarns or skein dyeing is conducted by suspending skeins of yarn in an agitated dye bath with possible additional movement of the skeins during dyeing. Fabric rolls are dyed by package dye technique, which is often carried out, in closed systems at elevated temperatures and pressures. Jig dyeing involves passage of a fabric piece back and forth from one spindle to another through a dye bath. Piece dyeing of textile fabrics can also be carried out. The above techniques are all batch processes.

Resist techniques such as tie-dyeing or batik limit dye migration to certain parts of the fabric. Discharge processes involve the use of bleaches or other chemicals to remove dye from selected areas of a dyed or printed fabric.

The pad-batch method is a special batch technique for application of reactive dyes to cellulose fibers in which the cellulose fabric is passed through a concentrated solution of reactive dye, followed by storage of the wet fabric in a vapor tight enclosure for 24 to 48 hours at room temperature. This allows time for diffusion and reaction of the dye with the fabric substrate prior to washing off unreacted dye. Dyeing is often carried out at 100°C or above. Dyeing with disperse dyes from aqueous solutions at 120°-130°C to achieve rapid dyeing is common. In addition, carriers are introduced to permit dyeing of polyester. These are usually aromatic organic compounds that can be emulsified in water and which have affinity for the polyester. Carriers must be removed after dyeing, as their presence in mill effluents presents a problem because of their toxicity.

The dye on the fabric is fixed by subsequent steaming of the substrate. Recently, foamed dye formulations have been applied to fabrics, thereby effectively reducing the dye liquor to fabric ratio and reducing energy and effluent treatment costs.

A number of chemical reagents (auxiliaries) as shown in Table 2.5 are added to the dye bath to alter in some manner the course of dyeing. Acids or bases may be added to the dye bath to induce charge formation in the fiber in order to increase dye diffusion or to promote reaction of the dye with the fiber as in the case of reactive dyes. In addition,
bases may be used to open up the structure of cellulosics to improve dyeing or to aid in dissolving of vat and sulfur dyes. Common inorganic salts such as sodium chloride or sodium sulfate may be added to a dye bath. These act as leveling agents, retard the rate of dyeing and give a more even dyeing. Surface-active agents such as anionic detergents can act as leveling agents and permit rapid and complete fiber wetting needed to give even dyeing. Water softening chemicals such as sodium hexametaphosphate are added to bind or chelate hardwater calcium or magnesium ions that may interfere with dyeing. Reducing agents are added to vat and sulfur dyes to react with the dye to give the leuco form. Added organic solvents and/or certain chemical reagents may increase the dye solubility and rate of penetration into the fiber. Urea has a similar effect in speeding dyeing of cellulosic and protein fibers.

<table>
<thead>
<tr>
<th>TYPE OF DYE</th>
<th>AUXILIARY CHEMICALS NECESSARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vat</td>
<td>Sodium hydroxide, Sodium hydrosulfite, Dispersing agent, Hydrogen peroxide, Acetic acid, Sodium perborate alternative</td>
</tr>
<tr>
<td>Direct</td>
<td>Sodium chloride, Sequestering agent, Sodium sulfate</td>
</tr>
<tr>
<td>Disperse</td>
<td>Orthophenylphenol, Butyl benzoate carriers, Chlorobenzene, Acetic acid, Dispersing agent, and many other carriers</td>
</tr>
<tr>
<td>Sulfur</td>
<td>Sodium sulfide, Sodium carbonate, Sodium dichromate, Acetic acid alternatives, Hydrogen peroxide, Acetic acid</td>
</tr>
<tr>
<td>Acid</td>
<td>Acetic acid, Ammonium sulfate, Ammonium acetate, Sulfuric acid, Sodium sulfate, Monosodium phosphate</td>
</tr>
<tr>
<td>Cationic</td>
<td>Acetic acid, Formic acid, Oxalic acid, Sodium acetate, Ethylene carbonate</td>
</tr>
<tr>
<td>Reactive</td>
<td>Sodium chloride, Urea, Sodium carbonate, Sodium hydroxide</td>
</tr>
</tbody>
</table>

Printing is a specialized dyeing technique. In printing, the concentration of dye is higher, and the dye medium is thick and viscous to limit dye migration on the fabric, permitting formation of design or pattern. Natural and synthetic gums and thickeners are
used to provide viscosity and thickness to the dye paste. Heating of fabrics following printing is necessary to achieve good dye penetration into the fiber. Superheated steam is preferred, since wet fixation causes a faster rate of dye migration than dry heating methods.

2.3 LITERATURE SURVEY

2.3.1 Adsorption of organics from aqueous solutions:

Adsorption of organics from solutions on activated carbons is one of the oldest and widespread applications of these materials. Earlier studies of activated carbon adsorption were carried out on fatty acids. However, now the work has been extended to a large number of aromatic compounds, Meenakshi [99] such as: - pesticides, herbicides, surfactants, polycyclic aromatic hydrocarbons, phenols and their derivatives, dyes, polar and non polar aliphatic compounds such as amines, halomethanes, humic acids such as gallic acid, tannic acid and fulvic acid. All these compounds are invariably found in all surface waters. Phenols and their substituted derivatives are present in the wastewater of several industries. Their removal from water has been the subject matter of a large number of investigations using activated carbon as the adsorbent. It is an essential part of water purification process. Chakravorti and Weber [27] used batch and fixed bed systems for the removal of phenol from aqueous solutions by activated carbons. Aggarwal et al [4], Miyahara, and Okazaki [102] using batch technique and Rajgopal et al [123] using dynamic adsorption technique studied the removal of aromatic nitro compounds from aqueous solutions on activated carbons. They observed that the removal depended upon the surface area of the carbon as well as on the amount of carbon – oxygen surface groups present on the carbon surface. The results of Miyahara and Okazaki could only partially be explained by the Freundlich equation. The adsorption of several amines on lignite and bituminous based activated carbons and on several commercial grade activated carbons and carbon blacks has shown that the adsorption is more for primary amines and decreases for secondary and tertiary amines depending upon the length and the number of chains in the amine.

The adsorption from solutions can be studied under two categories: adsorption of solutes, which have a limited solubility, and adsorption of solutes that are completely
miscible in all proportions. The adsorption of organics from aqueous solutions generally falls in the first category. Smolin et al. [142], Chobamu et al. [31], Allali, coworkers [8], and Tamamushi [148], studied the adsorption of several ionic surfactants from their aqueous solutions on activated carbons. They pointed out that adsorption involved two steps: monomolecular adsorption of the Langmuir type and multimolecular layer adsorption of the BET type. When the activated carbon surface was oxidized, the polar groups of the surfactant were attracted by the polar oxygen surface groups by electrostatic attractive forces and showed the formation of monomolecular layers, which were later, converted into multimolecular layers.

Removal of phenols from aqueous solutions of certain inorganics on granular activated carbon both before and after modification of the carbon surface by oxidation, degassing and methylation has been studied by Meenakshi [99]. The results suggest that the removal of these compounds by carbon is determined by the extent of the oxidation of the carbon surface.

Kitagara [81] used two commercial granular activated carbons for the adsorption of dyes from aqueous solution and observed that the adsorption data could be explained by Freundlich isotherms. The adsorption at a given concentration decreased with increase in the temperature although the rate of adsorption increased with increase in temperature. Addition of sodium chloride increased the adsorption rate and lengthened the breakthrough time. It was found that direct dyes did not adsorb as readily as other dyes.

Juang et al. [69] studied the adsorption of eight phenolic compounds from aqueous solutions on activated carbon fibers. Chlorinated phenols have been found to adsorb in larger amounts compared to methyl substituted phenols. Langmuir equation gave the poorest overall fit while the Freundlich equation was better although it also showed deviations at lower concentrations.

Vidic and coworkers [152], Abuzad and Nakhla [2] observed that the adsorption capacity of granular activated carbon for several phenolic compounds is highly influenced by the presence of molecular oxygen. The adsorption capacity of a carbon for 2-methyl phenol was enhanced by about 200% in the presence of oxygen.
Hidalgo and coworkers, Bansal and Randhawa, Lee et al, Anderson et al [54,23,87,10] studied the removal of aromatic compounds by activated carbons using static and dynamic adsorption methods. These workers observed that the adsorption capacity was related to surface area, pore volume and pore size distributions of the activated carbon. The adsorption was enhanced when the solution contained inorganic salts.

Mahajan et al [94] studied the adsorption of phenol from dilute solution on porous and non-porous carbons and observed that the uptake of phenol by non-porous carbons per unit area was determined by the nature of the carbon surface. The uptake of phenol decreased on surface oxidation of the carbon.

Puri and coworkers, Seidi and Kriska, Drozhalina & Bulgakova [118,135,37] while studying the adsorption of phenol by activated carbons and carbon blacks from aqueous solutions, observed that the adsorption was reversible at moderate concentrations and could be used to calculate the surface area of the carbons.

Jankowska et al, Groszek et al, Koltesev et al, Badnar and Nagi [64,50,83,22] studied the adsorption of phenol from dilute aqueous solutions and found that the adsorption was determined by the pore size distribution of the activated carbon. The carbons associated with finer micropores had better adsorption capacity.

Huan Ching K'O Usueh [59] studied the treatment of textile wastewater by physiochemical methods. It was pointed out that the major components in dyeing wastewaters are dyes, surfactants, starch, chemical aid and suspended solids. Dyes are divided into hydrophilic and hydrophobic. The former is removed effectively by activated carbon and Chlorine, while the latter is removed by floatation. Surfactants are removed by activated carbon or floatation. Starch is removed by flocculation. A treatment scheme was designed using the unit process of floatation, flocculation-settlemnet, sand filter, and activated carbon. Results showed that water from cotton dyeing and processing unit when treated as above could be reused as effectively as river water while for rinsing process the treated water was not as good.
The removal of several halomethanes such as CHCl₃, CHBr₂, CHCl₂ Br, CHClBr₂, from aqueous solutions by granulated active carbon (GAC) was investigated by Youssefi and Faust[162]. The adsorption was maximum for bromoform and least for chloroform. The break through curves followed the order CHCl₃ > CHCl₂ Br > CHClBr₂ > CHBr₃.

R. Hirai, Sakoda and Mullins et al [130] evaluated the performance of several commercially available active carbons for the removal of trihalomethanes from aqueous solutions. The study indicated that adsorption is a function of the nature of the carbon surface.

Storey and Schroeder [145] studied that granular carbon adsorption worked well for some textile wastewaters, whereas for others it was found that a portion of organic removal occurred from physical filtering rather than an adsorption mechanism.

Bauer, Siergrun, Kiesel, Brigitte, Schuster, Herbert, and Wenige [24] treated wastewater-containing dyes in solution or colloidal form by adding fly ash. The solution containing organic dye of concentration 100mg/l at pH 7.0-1.5 was mixed with ash for five minutes. After sedimentation and filtration the dye, removal efficiency was found to be 90-100%.

Perrich and Parish [116] recommend the use of activated carbon for removing dye color from affluent of textile dyeing and finishing industry before letting it flow into streams or municipal sewerage since it is economical as it can be regenerated more than ten times. It has good adsorption qualities for most organic compounds. It has dual properties of large surface area and high degree of surface activity.

Tong, Buging, Yao, Pingping [150] studied the adsorption of anionic dyes in wastewater (at <100mg/l) on Al₂O₃-MgO and activated carbon granules. It was found to be 131-mg/gm and 31 mg/g respectively at 30 degrees celsius. The adsorption efficiency on the outer and inner surface was 12%-88% for Al₂O₃-MgO and 15%-85% for granular activated carbon respectively.
Huang, C.P, Wirth, P.K. [60] studied two treatment systems based on economical aspect. They used powdered and granular activated carbon. Powdered activated carbon was found to be more effective in adsorbing Cd$^{2+}$ than granular activated carbon. The rate of Cd$^{2+}$ removal at pH 7 was proportional to the Cadmium concentration, the carbon dose and available surface sites. Used activated carbon was effectively regenerated with strong acids (eg. HCl, HClO$_3$ and H$_2$SO$_4$).

A study of the adsorption of water-soluble dyes on activated carbons having different porous structure was conducted by Luposliku, F.G. Mamcherko, and A.V. Ropot V.M [91]. The adsorption of direct blood red (I) and acidic anthroquinone blue (II) dyes were successfully adsorbed on active charcoals of different porous structure and non-porous carbon black.

The removal of chromium (VI) from aqueous solution by adsorption on a homogenous mixture of fly ash and china clay (1:1) was studied by Panday, K.K., Prasad Gur, Singh, V.N. [115] at various (chromium VI) concentrations, retention times, pHs' and temperatures. The Langmuir constants were determined graphically. Maximum removal of chromium (VI) was observed at pH 2.0 and 30±1$^0$.

Mckay [97] evaluated a model to explain the adsorption of selected dyes on activated carbon. The feasibility of activated carbon treatment of dyehouse wastewaters frequently depends on costs associated with regeneration of activated carbon. Thermal regeneration has been the primary means of regeneration of spent carbon.

Allen S.J., Mckay G., Khader, K.Y.H. [9] studied the adsorption of Basic Yellow 21 by sphagnum peat moss and evaluated the result in relation to its use in industrial wastewater treatment. The adsorption process was seen to be controlled by intraparticle size diffusion of the dye and was dependant on pore size distribution.

Adsorption characteristics of four types of organic dyes in aqueous solution on seven silica containing mixed oxide gels were investigated by Kaneka, Shaji, Saitoh, Hiwshi, Maejima, Yoshio Nakamura, Motoshi [76]. It was observed that CI Basic Red 18 adsorbed well on all the gels. Silica –magnesia, which was prepared by homogenous
precipitation showed higher adsorptive ability for all the dyes than other adsorbents. The initial pH of the dye solution, the composition of gel, precipitation methods of the gels affected the adsorbative ability.

Adsorption of four dyes; namely Basic Red 22, Basic Blue 69, Acid Red 114, and Acid Blue 25 onto bagasse pith were studied by Mckay, G., El Guendi.M., Nassar, M.M. [98]. Effect of pith particle size, dye concentration and temperature were observed. The data were analysed using Langmuir, Freundlich and Jossens Isotherms.

Liu, Manjing, Kang, Weijun, [90] observed the use of corn bran for removal of Hg from wastewater and found it to be an effective, simple and inexpensive treatment of wastewater. Corn bran gave more than 99.0% removal of Hg at pH 2-8 from water containing 10 mg Hg/l.

Mittal and Venkovachar [101] studied the adsorption of Rhodamine B (basic violet 10) and Sondolan Rhodine (acid red 1) and found that sulfonated coal exhibited moderate removal potential for both dyes. Desorption and regeneration studies using 1N H$_2$SO$_4$, CH$_3$ COOH, HCOOH indicated that the adsorption of Rhodamine B appeared to be chemical rather than physical or ion exchange whereas adsorption of Rhodine was physical to some extent with the absence of ion exchange mechanism.

El-Guendi Mohammad S. [43] observed adsorption of basic dyes onto natural clay in batch adsorbers. Basic blue 69 and Basic red 22 were the dyestuffs adsorbed onto natural clay. A homogenous surface diffusion model (HSDM) was developed to explain the concentration –time curves.

Imai, Takeshi, Fujimura, Eiji, [62] experimented on color removal from dyeing industry wastewater by adsorption of dyes on cationised cotton and paper. The wastewater contained 100 ppm Direct Black 38. 40ml wastewater was contacted with one gram of adsorbent for 24 hrs. The color removal was 48.5% vs. 97.3% for untreated cotton and treated cotton respectively and similar trend was observed for paper and cationized paper.
Diamado Polyos, Evan, Ioannidis, Socarates, Sakellara Poulos, George, P. [36] examined the use of flyash to remove As (V) from water or to restrict its movement in solid wastes or soil. Experiments were performed to evaluate the removal efficiency of lignite-based flyash. Both adsorption and desorption experiments were done at pH 4, 7, and 10. Results indicate that arsenic can be removed from water yet the degree of removal depends markedly on pH. Removal at pH 4 as demonstrated by adsorption isotherms was significantly higher than that at pH 7 and 10. For 80% arsenic removal the solid phase concentration at pH 4 was four times greater than at the other two-pH levels.

Lin [89] studied the effect of powdered activated carbon particle size on removal of color from Disperse dye and found that multilayer BET isotherm was better fit than monolayer Langmuir and Freundlich models. He also carried on the adsorption of Disperse dye Red 60 on various absorbents as activated alumina, granular activated carbon (GAC), saw dust and powdered activated carbon (PAC). Activated alumina and PAC were found to be better adsorbents for color removal than GAC and sawdust.

Viraraghvan, I., Dronamraju, Murali, [154] examined the use of fly ash in the removal of Cu²⁺, Ni²⁺, and Zn²⁺ from wastewater. The effect of contact time, pH concentration of adsorbate and temperature on the adsorption process were studied. Fly ash was an effective adsorbent. The contact time necessary to attain equilibrium was two hours maximum. Adsorption occurred at pH of 3.0-3.5. The Langmuir and Freundlich models were applicable to the adsorption data of Cu²⁺, Ni²⁺ and Zn²⁺. Thermodynamic parameters suggested the exothermic nature of the adsorption process.

K.C., Krishnaiah, Lakshmi Narayan Rao, K. and Ashutosh [70] have studied color removal from a dyestuff industry effluent using activated carbon. They identified the best commercially available activated carbon to remove the color of the dye in wastewater from dye using and dye manufacturing industry.

Adsorption of acid and basic Dyes on asbestos having charged parts was conducted by Hyedoh, Fiminori et al. [61] Eosin Y and Methylene Blue, acid and basic dyes were adsorbed on asbestos of varied kinds at room temperature.
In a work on removal of dyes from textile manufacturing wastewaters by adsorption on soot Rashed, Iaar Al-Alm, El-Komy, M.A., Metawally M.A. [125] have described substantial copper removal from textile effluents containing D Rimaline Violet X-2R, Reacto FIX-Yellow ME3-RL, Reacto Fix Supra Green M-BL, Cibcron Yellow F3-RL, and Procion Rubine MXB by adsorption on soot. Adsorption capacity of soot has been compared to that of powdered activated carbon. Adsorption isotherms have been given.

Dai and co-workers [32] examined the effect of zeta potential on the adsorption of anionic (carmine) and cationic (methyl green and methyl violet) dyes from aqueous solutions. The results showed that the adsorption of anionic dye increases on increasing zeta potential of the carbon surface making the carbon surface positive whereas decreasing zeta potential (lower than $-30\text{mV}$) enhances the adsorption of cationic dyes on carbon surface.

Viraraghavan and Ramakrishna [153] investigated adsorption of dyes on a low cost adsorbent and found that adsorption followed Langmuir and Freundlich adsorption isotherms. The adsorption of the basic dye was better as compared to that of acidic dye.

A research on dye removal from wastewater by activated carbon from leather buffing dust was conducted by Shanmuga Sundaram and Sekaran G [136]. It was based on utilization of solid waste generated from leather industry for removal of dye in aqueous solution. Buffing dust generated from leather industry was taken as a source for obtaining activated carbon for removal of dyes from wastewater. The removal of dyes by adsorption on sepiolite was studied by Zhang, Qing, Chen Yong, [165] using several aqueous solutions of dyes. The adsorption capacity of sepiolite and the effects of particle size, pH value, and temperature and adsorption time were discussed. The isotherms of adsorption on sepiolite were presented for five different dyes.

Removal of dioxins and heavy metals by a moving bed adsorber using activated carbon was studied by Tsuboi, Horushito, Ogaki and Yoji. [151]. The advantages of a moving bed adsorber system for recovering polychlorinated dibenzodioxins,
polychlorinated dibenzofuroxin and heavy metals from solid waste incinerator gases are described.

Singh, Vinay K, Tiwari, Prem N, [140] studied the removal and recovery of Cr (VI) from industrial wastewater. In this study carbon slurry generated as a waste material in naphtha based ammonia plant has been used as an adsorbent for removal of Cr (VI) from aqueous solutions in different experimental conditions. The removal was favorable at low pH, with maximum removal at pH 2.5. The effects of concentration and temperature have also been reported. The applicability of Langmuir isotherm for this system has been tested at different temperatures. Thermodynamic parameters indicate the endothermic nature of Cr (VI) adsorption on carbon slurry. Recovery of adsorbed Cr (VI) for reuse has also been reported.

Yoshida, Hiroyuki; et al [161] made their contribution by adsorbing direct dye on cross-linked chitosan fiber. They found the recovery of direct dye by adsorption on cross-linked chitosan fiber technically feasible.

Sojka-Ledakowicz et al [143] studied the adsorption of heavy metals from dyeing wastewater onto composite filters. Removal of Cd²⁺, Cu²⁺, Hg²⁺, Co²⁺, Cr³⁺, Cr⁶⁺ from after treatment baths was studied. Based on the literature chitosan exhibited high capability of heavy metal adsorption. Studies were carried out from the solutions (1:2) of reactive and metal complex dyes using composite filters with chitosan as an active component. Results were presented in a form of sorption isotherms of Cu²⁺, Co²⁺, Cr⁵⁺ and Cr³⁺ at equilibrium state. The usefulness of composite filters in the removal of these heavy metals from dye solutions was demonstrated. Sorption capability of chitosan in filters was determined with reference to Cu²⁺, Co²⁺, Cr³⁺ and Cr⁶⁺.

Fang, Chunya, [44] compared the absorbability between dye and phenol on activated carbon. Two dissimilar molecules, a large molecule cationic dye and phenol, were selected as adsorbates and their adsorption behavior on activated carbon was studied. It showed that the dye was more strongly adsorbable than phenol. The adsorbability of the dye was found to be proportional to pH, but that of phenol had maximum adsorption at neutral pH.
Namasivaym, C. Arasi [107] worked on waste red mud, an industrial by product, generated during the processing of bauxite ore. This was recycled for the adsorption of Congo Red from aqueous solution. Adsorption was studied using the parameters such as dye concentration, adsorbent dose, agitation time and pH. The data obtained obeyed both Langmuir and Freundlich isotherms. The adsorption capacity of the red mud for the dye was 4.05 mg/g. The adsorption was found to be nearly complete at pH 2.0.

Nagai, Kenichi, Hama, Tashio [109] cross linked graft polymers of starch and acrylic and graft polymers of poly vinyl acetate and acrylic to give water adsorbing polymers for removal of heavy metals ions like Cu$^{2+}$ from solution.

In studies conducted by Alberts, James J, Weber Marian F and Evans David W on adsorption of As(III) by coal fly ash [16] was preferentially removed from solution relative to As(V) at acid pH values. The concentration of As in receiving waters rapidly returned to levels found in the source waters for both trivalent and pentavalent forms. The maximum concentration of As(III) recorded in ash basin outlet was 9.3 mg/L which was in tune with water quality criteria.

Katoaka, Katsuyuki [77] examined the process of removal of phosphorous from water with granular adsorbents. The adsorbents were made by addition of highly water-absorbing polymers to phosphorous – adsorbing granules (e.g. Fe(OH)$_2$ and Al(OH)$_3$), activated carbon and cement at hydrated conditions followed by kneading and granulation of the mixture. The process comprises removal of phosphorous from phosphorous containing water by using the adsorbents. The adsorbents and process are used for removal of phosphorous from rivers or lakes wastewaters etc.

Kanan, N. Srinivasan, T. [75] studied the removal of copper from aqueous solution by using rice husk carbon and wood charcoal. The effect of initial concentration of Cu (II), contact time, dose of adsorbent and pH on the extent of removal of copper was studied. A decrease in initial concentration and increase in contact time and dose of adsorbent was found to increase in percentage removal of Copper. Wood charcoal was found to be best low cost carbonaceous adsorbent material for removal of copper from aqueous solution.
Naito, Harusuke et al [105] used agents comprising carbonized carbonaceous materials coated with powder or granulated carbon for removal of dyes from wastewater. These agents removed yellow dyes in wastewater from a fiber dyeing industry.

Dye adsorption on mesoporous activated carbon fiber was studied by Sasaki, Masahiko et al.,[133] It was found that mesoporous activated carbon fibers highly adsorbed dyes with large molecular size whereas microporous activated carbon fiber scarcely adsorbed these dyes. The adsorption amounts of these large molecular dyes on mesoporous activated carbon decreased by acid treatment.

Adsorptive removal of Methylene Blue from aqueous solutions using activated carbon was studied by Goyal, M., Rattan, V.K., Bansal, R.C. [49] It was found that adsorption of Methylene Blue was more on granular activated carbon as compared to fibrous carbon. This may be due to the difference in chemical nature of the carbon surface and not just due to the difference in surface area.

The adsorption of a reactive dye on chitosan has been investigated by Annadurai, G. Krishan, M.R.V. [15]. The results offer an attractive method of treatment of water with effluents within acceptable limits of coloring matter. The effects of several factors governing adsorption, such as adsorbent concentration, adsorbent size, temperature and pH had been observed in this study. Desorption of dye at different temperature and pH was investigated.

The ability of coconut fiber pith carbon to remove Cr (VI) from aqueous solution by adsorption was studied by Manju, G.N., Anirudhan, T.S. [96] The extent of removal was found to be dependent on sorbent dose, initial concentration, pH and temperature. The adsorption process was exothermic with maximum adsorption of 99.2% at 30° C for initial concentration of 50mg L⁻¹ at pH 2.0. Desorption studies revealed that spent adsorbent could be regenerated and reused.

Lima, L., O Livares, S., [88] examined the adsorption of two tannin adsorbents. Evaluation of the sorption process showed that the Cr (VI) tannin molecule binding is the principle responsible for Cr (VI) adsorption. High sorption capacities were registered for
both sorbents at pH 2. Influence of different ions present in water was examined. High adsorption capacity was reported in sea and tap water samples and 90-94% adsorption in distilled water.

Coal burning plants produce large amounts of fly ash as a residue. Fly ash has been used in construction, agriculture, metal recovery and water pollution control. Ayala, Julia, Blanco Francisco, Rodriguez, Perilope, Sancho Jose, [20] considered the efficiency of fly ash in the removal of heavy metals (Cd$^{2+}$ and Cu$^{2+}$). The fly ash was shown to be an effective metal adsorbent for these two metals. Adsorption capacity increased as metal initial concentration decreased.

The ability of 15 coniferous barks for removing toxic heavy metal ions were investigated by Seki, K, Saito N, Aoyama, M. Chokkaido. [137] The barks considerably varied in the adsorption ability to each metal ion. Adsorption of Cd$^{2+}$ was greatly affected by pH of the solution and initial cadmium concentration in solution. The adsorption of Cd$^{2+}$ followed Freundlich isotherm. The continuous column experiments indicated that the water had retained 10.1-14.2 mg cadmium adsorbent until the column breakthrough level was attained in the columns.

Khattri S.D. Singh, M.K. [79] investigated the capability of sagaun sawdust for removing basic dyes (Crystal Violet, Methylene Blue, Malachite Green, and Rhodamine B) from aqueous solution. The effect of system variables such as concentration, temperature, pH and particle size was studied. The maximum removal was found to be 89% at concentration 6mg L$^{-1}$ temperature 30$^\circ$C, and pH 7.5. The dye adsorption followed Langmuir isotherm.

Shukla Ramji and Singh, Anju [139] studied adsorptive removal of dispersed dye Malachite Green from dyeing waste water by a combination of chiten, activated charcoal and alumina.

Adsorption of binary dye solution onto activated carbon was studied by Cham Jia-Ming et al [28]. The adsorption and desorption behaviour of Mustard Yellow and Red binary dye mixtures by granulated activated carbon from wastewater have been observed.
Adsorptive removal of Direct Blue 2B from textile waste water by cross-linked polyvinylpyrrolidine and wood charcoal have been tried by Subramaniam, E.; Muthuswamy, M.; Rajan, K. Palanivel [146].

The potential of sone sand from sone river, Sonebhadra, UP (India) was investigated by Khattri S.D. Singh M.K [78]. It was found to be an effective adsorbent to remove dyes from aqueous solution. The effects of different types of dyes, particle diameters of adsorbent, dye concentration, pH of solution and temperature on best available adsorbent have been evaluated. The applicability of Langmuir and Freundlich isotherm suggests considerable adsorption of the dye molecules on the outer surface of the adsorbent.

The adsorption of reactive dyes was studied in batch system using granular activated carbon as adsorbent by Moriera, R.F.P.M., Kuhnen N.C., Peruch, M.G [103]. Dye adsorption in aqueous solution was evaluated under constant agitation, and temperature. The adsorption for each dye on activated carbon was determined.

Asthana, R.K., Singh, R.N., Tripathi, J.N. [19] studied the effect of concentration on removal of toxic heavy metal Pb(II) from water and wastewater by adsorption technique. In a standard stock solution of Pb(II) prepared by dissolving a known amount of Pb(NO₃)₂ in distilled water it was observed that at a temperature of 30°C (+), (-) 0.1°C and pH 6.0 and particle size of < 0.53 um china clay gave 100% adsorption at 2.0 ppm concentration.

Removal of dyes (Crystal Violet, Methylene Blue, Malachite Green, and Rhodamine C) from aqueous solution at different concentration, pH and temperatures by neem sawdust was carried out successfully by Khattri, S.D. Singh, M. K. [80] The percentage of dye adsorbed by neem sawdust decreased from 91.56 to 78.94 and 84.93 to 71.25 for crystal violet and malachite green respectively. With increase in dye concentration the adsorption of dyes decreased. With increase of temperature from 25 to 45°C the equation data followed Langmuir model of adsorption.
An overview on textile dye wastewater treatment has been given by Pai Malankar, Jayesh [114]. Carbon adsorption of dyes; ozonisation; electrochem technology; and powdered carbon-activated sludge system have been discussed by them in the study.

Sciban, Marina B, Klasnja, Mile T, Technoloski, Fak, [134] established that Chromium ions could be adsorbed from water by wood sawdust and wood constituents with different efficiencies. Optimum conditions for Cr⁶⁺ adsorption by poplar and fir sawdust, lignin, cellulose were established. Langmuir and Freundlich adsorption isotherm were determined. Adsorption of Cr⁶⁺ ions was found to be more efficient by lignin, than by wood sawdust and in turn, by cellulose. In all cases adsorption was well described both with Langmuir and Freundlich adsorption isotherm, except in case of adsorption by poplar sawdust, which was successfully described by Freundlich equation.

Sumanjit, Prasad, N. [147] experimented on rice husk ash, a waste from rice mills, using it as an adsorbent for removal of dyes from aqueous solution of textile dyes. The adsorption capacity of rice husk ash for five aqueous acid dye solutions was determined. The adsorption data fitted well to Freundlich and Langmuir Isotherms. The effect of contact time, pH, adsorbent concentrations and rate constant for each dye was calculated.

Activated carbon prepared from coconut tree sawdust was used as an adsorbent for the removal of Cr(VI) from aqueous solution by Selvi K, Pattabhi S, Kadirvelu K. [138] It was observed that adsorption of Cr(VI) was pH dependant and maximum removal was possible in acidic pH range. Desorption studies were carried out using 0.01-1 M NaOH solutions.

Industrial wastewaters from textile fiber and paper industries were purified and decolorized by treatment with an adsorbent consisting of a polymer solvated gel by Hoase, Jaroslav, Koiser, Leo E, and Schedegger Hans [56]. Five liters of green colored liquor containing several dyes and dyeing assistants was treated for three minutes with twelve grams of a polymer gel (surface area 165 m²/g). It was found that the green liquor was completely decolorized.
E.A. El–Sharkawy [40] studied the adsorption of textile dyes on to activated carbons synthesized from solid waste. Powdered wood of eucalyptus obtained as a solid waste was carbonized at 873 K in a nitrogen flow. The resulting products were activated with steam, zinc chloride and phosphoric acid to obtain three series of activated carbon. The textural properties, including surface area, mean pore radius and total pore volume, were examined. The adsorption power of the prepared samples for decolorization of Remazol Brilliant Blue (RBB) and New Coccine (NC) dyes, present as carcinogenic materials in wastewater was studied. The Langmuir and Freundlich equations were all applied satisfactorily for the calculation of various adsorption parameters. It was found that the structures of the two dyes and the types and amounts of adsorbents employed had a considerable influence on the adsorption parameters estimated.

Annadurai G, Juang RS and Lee DJ. [13] studied the effects of particle size (0.5-1.0 mm), temperature (30-60 degrees C), and solution pH (7-9) on the adsorption equilibrium of dye Rhodamine 6G by activated carbon in batch modes. The isotherm data could be well described by the Langmuir equation. Under the ranges tested, a maximum adsorption capacity of 44.7 mg/g was obtained.

Sivaraj R, Namasivayam C, Kadirvelu K. [141] observed the effectiveness of orange peel in adsorbing Acid violet 17 from aqueous solutions keeping track of the function of agitation time, adsorbent dosage, initial dye concentration and pH. The adsorption followed both Langmuir and Freundlich isotherms. The adsorption capacity was 19.88 mg/g at initial pH 6.3. The equilibrium time was found to be 80 min for 10,20,30 and 40 mg/l, dye concentration respectively. Maximum desorption of 60% was achieved in water medium at pH 10.0.

Johnson, P.D., Watson M.A. Brawn, J. Jefcoat, I.A. [67] studied the ability of peanut hull and peanut hull pellets to adsorb Copper from dilute aqueous metal ion solution in batch and fixed bed systems. Copper uptake by this media was examined and effect of pH and pellet size on rate and extent of copper captured was observed. Langmuir and Freundlich isotherm theories were determined. The Langmuir model best represented equilibrium isotherm data. 75% of Copper removal occurred within the first 20 min, 92% removal was affected within 50 min. The rate of uptake was optimum at pH 5. It was seen
that overall capacity of palletized peanut hulls was higher than for unmodified peanut hulls. Due to their demonstrated ability for Cu²⁺ uptake and favorable structural characteristics, palletized peanut hulls could gain use as low cost product for adsorption.

Rao M., Parwate A.V., Bhole, A.G. [125B] studied the efficiency of low cost adsorbent (fly ash, bagasse, wheat straw dust, sawdust, coconut jute) to remove Ni²⁺ from aqueous solution. Results were compared with adsorption by powdered activated carbon (PAC) in batch adsorption process. Factors affecting adsorption (pH, contact time, adsorbent dose, initial Nickel concentration, adsorbent particle size) were examined. The order of selectivity was PAC > sawdust > fly ash > wheat straw dust > coconut jute > bagasse. PAC followed Langmuir adsorption isotherm while other adsorbents Freundlich isotherm.

A study was conducted by Kulkarni, Jitendra R, Shrivastva, V.S. [85] to observe the adsorption of Nickel ions from aqueous solution using coconut husk. The dried and powdered husk was polymerized and it was found that the resin product so obtained was highly efficient in adsorbing. However, the extent of removal by adsorption was dependent on pH, amount of adsorbent used and time of contact. There was quantitative removal of Ni ions at alkaline pH (7-10) and 30 minutes time of contact. The aim of this study was the development of a new method for removal of Nickel ions from aqueous media. This method was found to be time saving and cost efficient.

Ricordel S, Taha, S. Cisse I, Dorange, G. [127] experimented by preparing carbon from peanut husk (PHC) and using it for adsorption of Pb²⁺, Zn²⁺, Ni²⁺, Cd²⁺. Chemical and physical characteristics of PHC were determined. The effects of particle size and carbon doses were evaluated by batch experiments. Pb²⁺ was found to have best affinity to PHC followed by Cd²⁺, Ni²⁺ and Zn²⁺. Thus, the order of sorption capacity of metal ions adsorbed was derived.

Adsorption behavior of heavy metals on two types of roasted coffee beans was studied by Mianmias W.A. Meyumi, Nakajina, Sugiko, Mitsue, Yuki, Miya Zawa, Kazue, Veno, Keiko, Hatori, Ai Miyajima, Sacko, Hoshno, Makie, Yoshida Shochiro, Takai, Nobubaru [100]. The coffee beans residue after extraction with hot water was suspended
in aqueous solution (pH=6.6) containing copper (II) and cadmium (II). The amount of heavy metal remaining in the solution was determined. It was found that the adsorption of Copper (II) was 60.5% and 79.6% for the two samples of coffee beans. However, when roasted coffee beans were washed with distilled water and then air-dried prior to the adsorption experiments the adsorption ratios increased to 92.2% and 92.6% for Copper (II) and 95.6% and 97.0% for Cadmium (II). Thus, the heavy metals were almost removed from aqueous solution using wasted coffee beans with washing and drying treatments.

Reddad, Zacaria, Gereste Claire, Andres, Yves, Le Cloirec and Peirre C Ecoleds [126] performed batch adsorption studies for several metal ions, namely Pb^{2+}, Cu^{2+}, Zn^{2+}, Cd^{2+} and Ni^{2+}. Sugar beet pulp generated by sugar refining factories was used as an adsorbent material. It proved to be an effective adsorbent for removal of heavy metal ions from aqueous solution. It was found that the metal removal was strongly dependent on pH of the solution.

Robinson T, Chandran B, and Nigam P [129] conducted a study on removal of dyes from a textile dye affluent by two agricultural waste residues, corncob and barley husk. These low cost bioabsorbants were used in a mixture of five textile dyes mixed in equal quantities. The effects of initial dye concentration, biosorbant particle size and dose of biosorbent on effective adsorbance were examined. The results showed that both barley husk and corncob were effective biosorbents for removal of textile dye. They also studied the adsorption of five reactive dyes in a synthetic textile dye effluent onto barley husks in static batch mode and in a continuous flow packed-bed reactor (CFPBR). The barley husks were found to remove 8 mg l^{-1} of dyes at concentration 100 mg/l. In CFPBR with a residence time of 11 min 90% adsorption was achieved from effluent.

T Robinson, B Chandran and P Nigam [128] studied the ability of two low-cost potential biosorbents, apple pomace and wheat straw to remove reactive dyes from synthetic effluent. The influence of initial dye concentration and particle size was assessed. Apple pomace adsorbed dye more quickly than wheat straw with both Langmuir and Freundlich isotherms being applicable to the adsorption data.
Three different agricultural residues (barley husk, sugarcane bagasse and wheat straw) were used to adsorb artificial dye effluent made from two different dyes (solar orange 7GLL and solar jade green FFB) by Chandran CB, Singh D and Nigam P [29]. The percentage of dye removal was observed in concentrations of dye varying from 50 to 200 mg/L. The effect of temperature ranging from 25° to 50° C and pH ranging from 6.0 to 12.0 on dye removal from substrates was also studied. The effective adsorption of substrates was calculated. The results of adsorption were very positive on all the three adsorbents.

Aksu Z and Donmez G [5] conducted a comparative study on the biosorption, characteristics, capacities and rates of different kinds of dried yeasts for remazol blue reactive dye from aqueous solutions. Among the nine yeast species, C. lipolytica exhibited the highest uptake capacity.

Electroadsorption of acilan blue dye present in textile effluents using activated carbon-perlite mixtures was studied by Koparal AS, Yavuz Y, Bakir Oğutveren U [84]. It was found from this work that this method combines all of the advantages of the activated-carbon adsorption and electrolytic methods for the removal of dyes from wastewater.

Mamdouh M. Nassar, Abd. El Hakim A. Daifullah, Yehia H. Magdy and Ebrahiem E. Ebrahiem [95] investigated the mechanistic aspects of sorption of Basic Blue-3 and Basic Red-22 on to cement kiln dust (CKD). Two forms of kiln dust were used in this study. Equilibrium isotherms to assess the maximum capacity of the two basic dyes on the two forms of CKD were evaluated using a computer program. It was found that Freundlich isotherm yielded an excellent overall fit.

Adsorption of Cu²⁺ and Pb²⁺ ions from aqueous solution on to activated carbon was studied by batch methods by Josnna Kapica, Robert Pelech, Jacek Przepiörsh and Antoni W. Morawsh [68]. It was seen that adsorption process proceeded in two stages:
an initial rapid stage followed by a slower one. It was found that the equilibrium isotherms could be analyzed using the Langmuir and Freundlich methods.

Fawzi Banat, Sameer Al-Asheh and Deaa Al-Rousan [45] utilized date-pits (an agricultural by-product available commercially) with and without activation, as an adsorbent for the removal of Zn$^{2+}$ and Cu$^{2+}$ ions from aqueous solutions. Activated carbons were prepared from date-pits by carbon dioxide activation at 700°C. The effects of contact time, pH, temperature and the adsorbent concentration on the removal of Zn$^{2+}$ and Cu$^{2+}$ ions were studied. The Freundlich isotherm model described the equilibrium adsorption data. The uptake of both metal ions increased on increasing the pH value of the system from 3.5 to 5.0 as well as on decreasing the temperature from 50°C to 25°C. The study demonstrated that date-pits without any physical or chemical pretreatment could be used as an effective adsorbent for the treatment of waters containing heavy metal ions such as Zn$^{2+}$ and Cu$^{2+}$.

Chib-Huang Weng. [30] studied the adsorption characteristics of an anionic azo dye (New Coccine) on to sewage sludge ash. Results showed that the ash could remove the dye effectively from aqueous solution. The adsorption rate was fast and could be expressed by the modified Freundlich equation. The ash adsorption capacities for the dye were in the range 3.25-5.70 mg/g and were affected by ionic strength and temperature. However, it was found that pH is the most important parameter affecting the adsorption characteristics. Decreasing pH, ionic strength and temperature increased the adsorption density. Thermodynamic parameters indicated that the adsorption was an exothermic process.

The feasibility of preparing chemically activated carbons from char obtained by the gasification of pine wastes has been studied by A.Garcia-Garcia, A. Gregorio, D. Baovida and I.Gulyurtlu [1]. The activated carbons prepared exhibited high benzene adsorption rates that increased with increasing micropore volume.

Eucalyptus barks harvested in Lebanon were used for the adsorption of pollutants such as heavy metal ions and dyes by R.Saliba and H Gauthier [120]. Washing with water or pretreatment with formaldehyde was performed on the bark powder. The adsorption
capacity of this material towards Cu$^{2+}$, Cr$^{3+}$, Cd$^{2+}$ and Ni$^{2+}$ was evaluated in a batch process for various parameters. The results obtained showed that the adsorption capacity increased with contact time, pH and initial metal ion concentration but decreased with temperature. Eucalyptus barks were also found to be very efficient for the adsorption of dyes (Acid Blue 25, Erichrome Blue Black B and Calmagite) because of the interaction between the hydroxy and amino groups of the dyes and the phenolic qualities of bark.

Low-cost banana and orange peels were prepared as adsorbents for the adsorption of dyes from aqueous solutions by AnnaduraiG, Juang RS, and Lee DJ [14]. Dye concentration and pH were varied. The adsorption capacities for both peels decreased in the order methyl orange (MO) > methylene blue (MB) > Rhodamine B (RB) > Congo red (CR) > methyl violet (MV) > amido black 10B (AB). The isotherm data could be well described by the Freundlich and Langmuir equations in the concentration range of 10-120 mg/l. An alkaline pH was favorable for the adsorption of dyes. Based on the adsorption capacity, it was shown that banana peel was more effective than orange peel. Both peel wastes were shown to be promising materials for adsorption removal of dyes from aqueous solutions.

Kadirvelu K, Senthilkumar P, Thamaraiselvi K, Subburam V. [74] prepared activated carbon (AC) from waste Parthenium and used it to eliminate Ni(II) from aqueous solution by adsorption. Batch mode adsorption experiments were carried out by varying contact time, metal ion concentration, carbon concentration and pH. The adsorption data were evaluated by using both Langmuir and Freundlich classical adsorption isotherms. The adsorption capacity calculated from the Langmuir isotherm was 54.35 mg Ni (II) per gram of activated carbon at initial pH of 5.0, temperature of 20 degrees C and particle size of 250-500 microns. Increase in pH increased percent removal of metal ion. Ni (II)-saturated carbon could be regenerated by HCl and reused.

Parthenium is a perennial weed distributed all over the country. Rajeshwarisivaraj, Subburam V. [122] experimented with carbonized parthenium activated with concentrated sulphuric acid and ammonium persulphate and found it to be effective in the removal of dyes, heavy metals and phenols. Variation in the percentage removal of adsorbates was observed with increase in the contact time. Among the adsorbates tested,
the affinity of the activated parthenium carbon was highest for Hg$^{2+}$, Methylene Blue and Malachite Green.

Demirbas E, Kobya M, Oncel S, Sencan S. [33] prepared activated carbon from hazelnut shell and used it as an adsorbent for the removal of Ni (II) from aqueous solution. Batch mode adsorption studies were carried out by varying initial metal ion concentration, agitation speed, and temperature and particle size. A contact time of 180 minutes was required to reach equilibrium. The equilibrium data were analyzed using the Langmuir and Freundlich isotherms. The characteristic parameters for each isotherm were determined. The Langmuir isotherm provided the best correlation for Ni (II) adsorption onto the activated carbon. Thermodynamical parameters revealed that the adsorption of Ni(II) is exothermic in nature.

Low cost carbon was prepared from palm nutshells, cashew nut shells and broomsticks by Rajavel G, Anathanaraynan C, Prabhakar LD, and Palanivel C. [121] using sulphuric acid. The activities of these carbons were compared with that of high cost commercial activated carbon. The effect of pH, time, and carbon dose were examined along with isotherm studies. The applications of these carbons were examined on color removal from both effluent samples and synthetic samples. It was proposed that all three adsorbents could be an attractive option for dye adsorption.

In a study conducted by Garg VK, Gupta R, Bala Yadav A, Kumar R. [47] formaldehyde treated and sulphuric acid treated saw dusts were used to adsorb malachite green at varying dye concentration, adsorbent dose, pH and agitation time. The adsorption efficiency of sulphuric acid treated sawdust was higher than formaldehyde treated sawdust. An initial pH in the range of 6-9 was favorable for the dye removal by both the adsorbents. Dilute solutions were effectively decolorized by the adsorbents. It was proposed that for both batch and stirred tank reactors sawdust could be an attractive option for dye adsorption.

Waranusantigul P, Pkethitiyook P, Kruatrachue M, and Upatham ES. [156] carried out laboratory investigations, on the potential use of dried spirodela polyrrhiza biomass (giant duckweed) as an adsorbent for the removal of the basic dye methylene blue from
aqueous solution. The result showed that as the amount of the dried spirodela polyrrhiza increased, the percentage of dye sorption increased accordingly. At pH 2.0 the sorption of dye was not favorable, while the sorption at other pHs (3.0-11.0) was remarkable. The dye removal time was influenced by the initial dye concentration.

Janos P, Buchtova H, Ryznarova M, [65] studied sorption of dyes from aqueous solutions onto fly ash. Brown coal fly ashes were tested as potentially low-cost sorbents for the removal of synthetic dyes from waters. It was shown that both basic (cationic) as well as acid (anionic) dyes could be sorbed onto the fly ash. The dye sorption decreased in the presence of organic solvents (methanol, acetone). The presence of oppositely charged surfactants exhibited a pronounced effect on the dye sorption.

Adsorption of metallic ions on wool was studied by Hilota, Sanae, Seguchi, and Kazuyoshi [55]. The uptake of wool and nylon fabrics with or without treatment with Chrome Violet was measured on a spectrophotometer. Heavy metal ions Cu$^{2+}$, Ni$^{2+}$, Cr$^{3+}$, were adsorbed effectively, the amount of adsorption depending on the ion type. The adsorption results suggested that metallic ions occupied the contusion part of polyelectrolyte polymers (wool and nylon 6). Dye treated fabrics in general caused a considerable increase in adsorption due to complex transition between dye and metallic ions.

Janos P [66] examined Iron humate (IH) as a new low-cost sorbent for removing basic dyes (Methylene Blue, Methyl Violet, Crystal Violet, Malachite Green, and Rhodamine B) from waters. The sorption of the dyes from aqueous solutions was described by a Langmuis isotherm. Iron Humate proved to be a good option for dye adsorption.

In a study conducted by Armagan B, Ozdemir O, Turan M, Celik MS. [17] the ability of sepiolite to uptake different reactive dyes was investigated. The dyes used in the experiments were Everzol Black B, Everzol Yellow 3RS H/C, and Everzol Red 3BS. A number of parameters of adsorption were investigated in order to establish the adsorption pattern of sepiolite. The effect of time, solid/liquid ratio, pH, temperature, and dye concentrations on adsorption were observed. Adsorption isotherms for different reactive
dyes were obtained using both natural and modified sepiolites. The adsorption by natural sepiolite appeared to have a little capacity for reactive dyes. The modified sepiolite exhibited ten times higher performance than the natural sepiolite.

Kadirvelu K, Kavipriya M, Karthika C, Radhika M, Vennilamani N, Pattabhi S. [73] carried out experimental work on different adsorption materials. Activated carbons were prepared from the agricultural solid wastes, coconut tree sawdust, sago waste, maize cob and banana pith and used to eliminate heavy metals and dyes from aqueous solution. Findings showed that adsorption of all dyes and metal ions required a very short time and gave quantitative removal. It was observed that all carbons were effective for the removal of pollutants from water. Since all agricultural solid wastes used in this investigation are freely, abundantly and locally available, the resulting carbons are expected to be economically viable for wastewater treatment.

Inbaraj BS and Sulochana N. [63] observed the effect of carbonized jackfruit peel as an adsorbent for the removal of Cd (II) from aqueous solution. Jackfruit peel was treated with sulphuric acid to produce a carbonaceous product. Adsorption data was examined on Freundlich and Langmuir isotherms. Effect of parameters like metal concentration and pH on metal removal was experimented with. It was observed that complete recovery of the adsorbed metal ions from the spent adsorbant could be achieved.

Koby M. [82] experimented on removal of Cr (VI) from aqueous solutions by adsorption onto hazelnut shell activated carbon. Varying degrees of parameters such as pH, initial Cr (VI) concentration and temperature were observed. Adsorption capacity was calculated from Langmuir isotherm as 170 mg/g at an initial pH value of 1.0 for the 1000mg/l Cr (VI) solution.

Goel J, Kadirvelu K, Rajagopal C. [48] undertook a study to investigate adsorption behavior of Hg (II) from aqueous systems on activated carbon in static and dynamic mode by varying initial Hg (II) concentration, adsorbent dose and pH. Removal of mercury obeyed the Langmuir and Freundlich adsorption isotherm models. The extent of removal of Hg (II) was found to be dependent on sorbent dose, pH and initial Hg (II) concentration. Mercury uptake increased from 72 to 100 percent with increasing pH from
2 to 10. A set of desorption studies was also performed for the metal ions with the aim of investigating the mechanism involved.

Roy Ajit Kumar prepared adsorptive material from eggshells boiled with 0.1N NaOH solution for ten minutes followed by washing the boiled shells with water to remove the alkali [131]. The thin film from the washed shells was removed manually. After drying the shells, they were powdered finely. This powder was then treated with a mixture of petroleum ether to remove the fat. The fat free eggshells powder was then dried again at 100° C for two hours. The egg shells could be used effectively as an adsorbent.

Brown NW, Roberts EP, Garforth AA, Dryfe RA [25] pointed out that adsorption is an attractive route for the removal of colored, toxic and non-biodegradable organics from wastewater as very low discharge standards can be achieved. In their paper they reported on the use of a novel carbon-based material, Nyex 100, as an adsorbent material for the treatment of dye house effluent. This adsorbent has low porosity but high electrical conductivity. These factors allow the adsorbent to be electrochemically regenerated a number of times with little drop in adsorption capacity. However, since it has low adsorptive capacity because of its small surface area it means that large quantities of adsorbent would need to be cycled within the process to treat the effluent volume generated in even small dye houses.

G A Lipei [46], conducted a study on determination of adsorptive power of coal ash towards Cr (VI). Coal ashes showed a characteristic adsorption for Cr⁶⁺ from acidic aqueous solution. The adsorption capacity increased with increasing Cr⁶⁺ concentration. The possibility of using coal ash for Cr⁶⁺ containing wastewater treatment was discussed.

K.Vasanth Kumar, S. Sivanesan and V.Ramamurthi [72] carried out experiments in batch process for the removal of methylene blue from its aqueous solution using pithophora sp, a fresh water algae as an adsorbent. The sorption capacity was found to be 45.017 mg/g at 30° C for an optimum solution pH of 3.25. The cations were found to be adsorbed into pithophora sp due to strong electrostatic force of attraction. The equilibrium data followed both Freundlich and Langmuir isotherm equation.
The adsorption of Basic Red 18 and Basic Blue 19 from aqueous solution by dried activated sludge was investigated in a batch system by Gulnaz O, Kaya A, Matyar F, Arikan B. [51] The activated sludge had the highest dye uptake capacity, for Basic Red 18 and Basic Blue 9, respectively, at pH value of 7.0 and a temperature of 20 degrees C. The equilibrium data fitted very well with both the Langmuir and Freundlich models.

Wheat bran, a by-product of wheat milling industries was converted into a cheap and efficient material by treating it with sulphuric acid and used for the adsorption of Cr(VI) from aqueous solution by Ozer A, Ozer D [112]. Effects of various parameters such as initial pH of solution, contact time, initial Cr (VI) concentration and temperature were studied. The sulphuric acid-treated wheat bran (STWB) gave the highest adsorption efficiency at pH 1.5. The equilibrium data fitted better to Langmuir isotherm model compared to Freundlich model at all the temperatures studied. The adsorption capacity increased from 91 to 133 mg/L with an increase in temperature from 20° C to 50° C.

The adsorption of reactive dyes on clinoptilolite was investigated by Armagan B, Turan M, and Ozdemiro [18] in series of batch and column adsorption experiments. Three reactive dyes (Everzol Black, Everzol Red, Everzol Yellow) were used in laboratory studies. Synthetic wastewaters were used and the adsorption ability of natural zeolite (clinoptilolite) and their modified form were examined. The adsorption results, in batch and column reactor, indicated that natural zeolite had limited adsorption capacity for the reactive dyes but substantially improved upon modifying their surfaces.

Ozturk N, Bektas TE. [113] studied the adsorbency of natural sepiolite, sepiolite activated by HCl, slag and powdered activated carbon. NaNO₃ solution (100 mg/l) was used in batch adsorption experiments for nitrate removal. Adsorbent dosages were varied from 5 to 20 gm/l solutions. An increase in adsorbent dosage increased the percent removal of nitrate. A series of isotherm studies were undertaken and the data evaluated for compliance with the Langmuir and Freundlich isotherm models. Experimental data showed that sepiolite activated by HCl was most effective for nitrate removal. Natural sepiolite and powdered activated carbon had lesser absorbency in comparison.
A study on adsorption capacity of various waste products was conducted by Nakagawa K, Namba A, Mukai SR, Tamon F. Ariyadejwanich P, Tanthapanichakoon W. Activated carbons were produced from several solid wastes, namely waste PET, waste tires, refuse derived from fuel and wastes generated during lactic acid fermentation from garbage. Activated carbons having various pore size distributions were obtained. The adsorption of organic compounds from aqueous solution on the activated carbons was determined to confirm the applicability of these carbons. Phenol and reactive dye, Black5, were employed as representative adsorbates. The characteristics of a typical commercial activated carbon were also measured and compared. It was found that the activated carbon with plentiful mesopores prepared from PET and waste tires had quite high adsorption capacity for large molecules. Therefore, they were recommended as useful adsorbents for wastewater treatment, especially, for removal of bulky adsorbates. Reife Abrahim, an expert in many aspects of dye waste water treatment has mentioned in the Dye Stuff And Environmental NJ, US of America the combined use of biological, physical and chemical methods such as absorption, reverse osmosis, ultra filtration, coagulation, flocculation reduction and oxygen in dye effluent treatment.

Ajmal, Mohmmad, Mohammad Ali, Yosuf, Rehana, Ahmad, Anees[12] found that magnifua indica seed shell had good sorption capacity for Cd²⁺, Zn²⁺, Ni²⁺, and Pb²⁺. Studies indicated that sorption for these heavy metals increased with increase in pH and a contact time of 90 minutes was found to be optimum. The effect of concentration shows that seed shell can remove most of the Cd²⁺, Zn²⁺, Ni²⁺, and Pb²⁺ from water and adsorption confirmed to Freundlich adsorption isotherm. The presence of NaCl interfered with the adsorption of Cd²⁺, Zn²⁺, Ni²⁺, and Pb²⁺.

The main objectives of water treatment are to produce high quality water that is safe for human consumption, has aesthetic appeal, conforms to state and federal standards, and is economical in production. One of the cheapest and best tools that help to achieve these goals is activated carbon. As seen above numerous laboratory studies dealing with Carbon Adsorption on different classes of dyes have been conducted to design dye waste treatment facilities.
2.3.2 Isotherms/Models/Equations

Isotherms are drawn to predict how much solute can be adsorbed by activated carbon. These represent the relationship between the amount adsorbed and the concentration at a constant temperature. They also provide some useful information about the adsorption process and enable determination of useful surface parameters such as surface area, pore size distribution and pore volume of the adsorbent. The adsorption equilibrium can be represented by several adsorption isotherm equations, more important being the Langmuir and the Freundlich isotherm equations. These are in common use for describing adsorption isotherms at a constant temperature for water and wastewater treatment applications [14,71,92,93,163,164] In environmental engineering the most commonly used isotherm is the Freundlich. The BET equation, and the Dubinin equation are frequently applied. Each individual type of activated carbon has its own isotherm curve and breakpoint characteristics. These help to give a design estimate for its adsorptive life.

**Langmuir Adsorption Isotherm:**

Langmuir equation was the first adsorption isotherm derived theoretically. It involves ideally localized monomolecular adsorption layers of adsorbate molecules with no intermolecular interactions.

Equilibrium data, commonly known as adsorption isotherms, are basic requirements for the design of adsorption systems. These data provide information on the capacity of the adsorbent or the amount required to remove a unit mass of pollutant under the system conditions.

The Langmuir adsorption isotherm has been successfully applied to many adsorption processes and it has been used in this study to explain the sorption of various textile dyes onto activated carbon. A basic assumption of the Langmuir theory is that sorption takes place at specific homogeneous sites within the adsorbent. It is then assumed that once a dye molecule occupies a site, no further adsorption can take place at that site. Theoretically, therefore, a saturation value is reached beyond which no further
sorption can take place. The well-known expression of the Langmuir model is given by the following equation:

\[ q_e = \frac{QbC_e}{1 + bC_e} \]  
(1)

A linear form of this expression is

\[ \frac{1}{q_e} = \frac{1}{Q} + \frac{1}{bQ} \frac{1}{C_e} \]  
(2)

where \( q_e \) is the amount of dye adsorbed per unit weight of adsorbent (mg/g), \( C_e \) is the equilibrium concentration of dye in solution (mg/l). The constant \( Q \) signifies the adsorption capacity (mg/g) and \( b \) is related with the energy of adsorption (L/mg).

A plot of \( 1/q_e \) versus \( 1/C_e \) yields a straight line of slope \( 1/bQ \) and intercept \( 1/Q \).

The essential characteristics of Langmuir equation can be expressed in terms of a dimensionless separation factor \( R_L \) which is defined by Al-Dega et al [6]:

\[ R_L = \frac{1}{1 + bC_0} \]  
(3)

where \( C_0 \) is the highest initial dye concentration (mg/L) and \( b \) is the Langmuir constant. \( R_L \) values indicate the shape of the isotherm. The \( R_L \) value between zero and one indicates favorable adsorption. [164]. \( R_L > 1 \) is unfavorable. \( R_L = 1 \) is linear. \( 0 < R_L < 1 \) is favorable. \( R_L = 0 \) is irreversible.

**Freundlich Adsorption Isotherm:**

Freundlich isotherm has been widely used for adsorption from solution phase. The empirical Freundlich equation based on a heterogeneous surface is given by equation:

\[ Q_e = K_fC_e^{1/n} \]  
(4)

where \( K_f \) is the Freundlich constant and \( n \) the Freundlich exponent. A linear form of the Freundlich expression [124] will yield the constants \( K_f \) and \( n \). Hence,
Log $q_e = \log K_F + \frac{1}{n} \log C_e$ \hspace{1cm} (5)

A plot of log $q_e$ versus log $C_e$ enables the constant $K_F$ and exponent $n$ to be determined.

$K_F$ parameter is relative to the adsorption capacity and $n$ refers to the process intensity.

The value of $n$ between 2 and 10 shows good adsorption. A plot of log $q_e$ against log $C_e$ gives a straight line, the slope and intercept of which correspond to $1/n$ and log $K_F$, respectively [124].

The difference in adsorption capacity between different dyes comes from different molecular structures of dyes and their different molecular weights.

**The Dubinin-Radushkevich Equation**

Dubinin and coworkers [39] have developed several equations that describe equilibrium adsorption of gaseous adsorbates onto different types of microporous carbon adsorbents with energetically homogeneous adsorption sites. These equations are based on the concept of volume filling of the micropores, which describes adsorption as a pore filling effect, rather than a layer-by-layer adsorption effect. One of these equations is the DR equation, which has successfully described the adsorption of many individual compounds onto carbon adsorbents [39]. The equation generally works well with single component vapors and with gas mixtures of one strongly adsorbed component and other weakly adsorbed components. The DR equation is presented below:

$$W = W_0 \exp (-mx_0^2 A^2)$$ \hspace{1cm} (6)

$W_0$ and $x_0$ can be determined by plotting the experimental adsorption isotherm data in the form of the characteristic adsorption equation:
By plotting ln (W) on the ordinate and $A^2$ on the abscissa, and applying a linear regression to the experimental data, $W_0$ and $X_0$ can be determined from the intercept of the ordinate and the slope of the linear regression line, respectively.

**BET Equation**

The theory of multilayer adsorption developed by Brunauer, Emmet and Teller [26] in 1933 and commonly known as BET equation has played an important and dominant role in adsorption studies. It enables determination of specific surface area of the adsorbent and the approximate value of heat of adsorption. The derivation of the equation involves extension of the Langmuir unimolecular layer concept to multimolecular adsorption and derived on the assumption that the forces acting in multimolecular adsorption are the same as involved in the condensation of vapours. Each of the adsorbed layer of molecules acts as a base for the adsorption of the second layer which in turn acts as a base for the third layer and so on. Only the first layer of adsorbed molecules, which is in direct contact with the adsorbent surface, is bound by adsorption forces originating from the surface of the solid. As these forces are short range, the molecules in the second and subsequent layers are not influenced by them. Therefore, the heat of adsorption in the second and higher layers is constant and equal to the heat of liquefaction of the adsorbate.

Based on these assumptions, Brunauer, Emmett and Teller [26] derived the equation which is represented as:

$$\frac{\rho}{V(p^*-p)} = \frac{1}{V_m C} + \frac{C-1}{V_m C} \frac{p/p^*}{V_m C}$$

(8)
Where $V$ is the volume of the adsorbate adsorbed at pressure $p$ and $V_m$ is the mololayer capacity (volume of adsorbate required to form a unimolecular layer), $p/p^0$ is the relative vapour pressure and $C$ is a constant given by:

$$C = \exp \left[ \frac{(E_1 - E_L)}{RT} \right]$$

(9)

Where $E_L$ is the heat of adsorption in the first layer and $E_1$ is the heat of liquefaction of the adsorbate. It can be seen that a plot of $p/[V (p^0-p)]$ versus $p/p^0$ will give a straight line, the slope and the intercept of which can give the values of $V_m$ and $C$. The monolayer capacity $V_m$ can be used to calculate the surface area of the adsorbent. BET surface area is considered to be an important parameter for surface studies of solids.

The plot between $p$ and $p/[V (p^0-p)]$ is linear only in the limited range of relative vapour pressures from 0.05-0.35. At relative pressures lower than 0.05 the equation is usually not valid because the effect of the energetic heterogeneity of the surface cannot be neglected while at higher pressures it loses its validity because of the combination of physical adsorption and capillary condensation.