CHAPTER-II

LITERATURE REVIEW

The literature available on the removal and separation of phenols and removal of dyes by various adsorbents is presented as under:

Removal of Phenols

Asthana and Bhatia\(^1\) studied the adsorption behaviour of phenol and p-cresol from dilute aqueous streams in a fixed bed column using cation exchange resin Dowex 50W-X8 and a bio-adsorbent.

Crooks et al.\(^2\), and Desmukh and Pangarkar\(^3\) have reported removal of phenols by polymeric adsorbents.

Adsorption and desorption of phenol on activated carbon and strong base anion-exchange resin were investigated in a fixed bed column by Goto et al.\(^4\). Phenol was effectively adsorbed on both adsorbents. Experimental breakthrough curves were compared with values calculated on the assumption of surface diffusion controlling step. Regeneration by sodium hydroxide or hydrochloric acid was effectively performed for the resin. The adsorption capacity of activated carbon decreased gradually during the repetition process of adsorption and desorption, while the capacity for anion exchange-resin remained constant.

Porous polymeric adsorbents based on the acrylic matrix have been investigated for their ability to remove phenolics
from the water by Reddy et al\textsuperscript{5}. The adsorbent showed reversible uptake of phenolic compounds and thus have a good application potential.

Adsorption of phenols and benzoic acid from dilute aqueous solution onto a macroreticular resin have been reported by Farrier et al\textsuperscript{6}.

Sorption of phenolic compounds on porous weakly basic anion exchanger based on acrylic matrix has been reported by Reddy et al\textsuperscript{7}.

Recently adsorption of phenol, p-nitrophenol and their binary, mixtures from aqueous solutions on Amberlite synthetic resin XAD-2 have reported by T. Devarafulu et al\textsuperscript{8}.

Various other anion exchange resins have been reported for the adsorption studies of phenolic compounds\textsuperscript{9-12}.

Kennedy\textsuperscript{13} has reported Amberlite XAD resin for the removal of phenol and p-chlorophenol from aqueous solution.

Vinylpyridine divinyl benzene co-polymer has been utilized for the removal of phenols\textsuperscript{14}.

Tributylphosphate and trialkylphosphine oxide containing resins\textsuperscript{15} have been studied for the adsorption and removal of phenols.

Mashowska et al. and Oberoi et al.\textsuperscript{17} have reported removal and recovery of 2-chlorophenol and other phenols using ion-exchange resins.
Removal of phenolic compounds (10-100 ppm) using Fe(OH)$_3$ impregnated saw dust in Fe(III) from has been studied by Singh and Misra$^{18}$. Effect of pH on recovery of phenolic compounds from water samples has been investigated. The phenols retained were quantitatively eluted with ethanolic sodium hydroxide solution and the cyclic use of the same column is reported.

Iron (III) hydroxide-loaded marble$^{19}$ was studied as an adsorbent to remove phenolic compounds from aqueous solution. The co-ordination of ligand with central metal ion occurs through the phenolic oxygen. Fe-marbel exhibits good adsorption capacity for phenolic compounds and the adsorption data follow Langmuir model as well as Freundlich model. The phenols adsorbed were quantitatively eluted with 1M NaOH solution. The column can be used for 4-5 cycles consecutively. The nature of phenol adsorption onto iron (III) hydroxide surface was elucidated on the basis of ligand exchange reaction of hexaco-ordinate iron(III) on the Fe-marbel surface (H$_2$O or OH ligand→phenol)

$$\text{ROH}+\left[\text{Fe}(\text{H}_2\text{O})_6\right]^{3+} \rightleftharpoons \text{H}_2\text{O}+\left[\text{Fe}(\text{H}_2\text{O})_5(\text{ROH})\right]^{3+}$$

$$\left[\text{Fe}(\text{H}_2\text{O})_5(\text{ROH})\right]^{3+} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ +\left[\text{Fe}(\text{H}_2\text{O})_5(\text{RO})\right]^{3+}$$

Chromatographic technique for the analysis of phenolic compounds has been reported by Law and Chan et al$^{20}$. Singh et al. have reported qualitative separations of phenolic compounds in the mixture on Whatmann No.3 paper strips impregnated with iron (III) diethanolamine$^{21}$ and iron
hexamine. Zinc silicate as a new adsorbent for paper chromatographic separations of phenols has been reported by Rawat et al. Clark suggested the use of ion-exchange papers for the separation of phenols. Stannic Molybdate, an inorganic ion-exchanger has been employed as an adsorbent for paper chromatography of some phenols.

Rawat et al. have reported detection and chromatographic separation of phenols on iron-hydroxide impregnated papers. H.F. Walten et al. have shown the possibilities of ligand-exchange for chromatographic separation. Separation of chlorophenols on cation-exchanger in Ce(III) form has been reported by Maslowska et al. Hydrated cerium oxide impregnated papers are reported for the separation of phenols. Iron(III) diethanolamine and iron(III) hexamine have been investigated for column chromatographic separation of phenols.

Recently synthetic inorganic ion-exchangers have been used in thin layer chromatography (TLC) of organic compounds. Nabi et al., have reported a semicrystalline inorganic ion-exchanger, stannic tungstate for thin layer chromatographic separations of phenolic compounds. Thin layer chromatography has application for the separation of phenolic compounds using various other adsorbents.

The ability of activated carbon, Filtrasorb 400, to adsorb various phenol and p-chlorophenol from aqueous solution has
been studied by Mckay et al.\textsuperscript{37}.

Zogorski et al.\textsuperscript{38} have studied operational parameters for optimum removal of phenolic compounds from waters by columns of activated carbon.

A comparative study of the sorption of phenol and p-chlorophenol from water has been performed using novel samples prepared by carbonization and subsequent activation of straw and used rubber tyres as well as conventional activated carbons based on coal, coconut shell and wood by streat et al.\textsuperscript{39}. The sorption kinetics of the straw and used rubber tyre based carbons are likewise identical to conventional carbons based on coal and wood but appreciably faster than the coconut shell sample selected for comparison.

Martin et al.\textsuperscript{40}, and Nikolenlo et al.\textsuperscript{41} have reported the removal of phenols by activated carbon. Bhatia and Kalam\textsuperscript{42} examined the effective diffusivity of phenol in activated carbon.

Daifullah et al.\textsuperscript{43} have tested the equilibrium removal of phenol (P), m-,p-cresol(Cr), 2-chlorophenol(2.Cp ), 4-nitrophenol (4-NP), 2,4-dinitrophenol(2,4-DNP)and 2,4-dichlophenol(2,4-DCP) by adsorption onto activated carbon prepared from apricot stone shells by chemical treatment with $\text{H}_3\text{PO}_4$. Uptake of phenols increases in the order P,Cr<2-CP<4-NP<2,4-DNP<2,4-DCP, which correlates well with respective increase in molecular dimentions and acidity and decrease in solubility of the sorbate.
Abnormality shown by 2,4-DNP as a drop in its removal, is due to strong adsorption at the entrance or inside certain pores thus limiting further diffusion of solute molecules and/or probable molecular sieve effect.

Caturla et al. have reported adsorption of substituted phenol on activated carbon. Aytekin studied application of polyanye adsorption potential theory to adsorption of phenolic compounds from water solution onto activated carbon.

Effect of pH and inorganic salts on adsorption of phenol from aqueous systems on activated decolouring charcoal has been studied by Halhouli et al.

Mostafa, Sarma and Youssef utilized activated carbon for the adsorption of phenol.

Rivera-Utrilla have reported comparison of activated carbons prepared from agricultural raw materials and Spanish lignites when removing chlorophenols from aqueous solutions. Competitive adsorption of substituted phenols by activated carbon developed from the fertilizer waste slurry has been reported by Srivastava and Tyagi.

The competitive effect on the uptake of various substituted phenols viz 2,4,6-trinitrophenol, 4-nitrophenol, 4-chlorophenol and 1,3 dihydroxybenzene on the carbonaceous adsorbent developed from fertilizer waste, has been studied using the Langmuir model for bisolute-system and also by the Jain and Snoeyink.
modified model. For the four phenolic compounds the rate is higher for 2,4,6-trinitrophenol than for the other substituted derivatives; their relative rates generally decrease in the order of 4-nitrophenol, 4-chlorophenol and 1,3- dihydroxybenzene.

Rayalu and Srivastva\textsuperscript{50} conducted investigation related to production and adsorptive properties of fibrous active carbon produced from jute fibers. The results reveal that it is possible to produce activated fibrous carbon by impregnating the fibres with certain lewis acids followed by the steps of carbonization and activation. The surface area of the carbon lies in the range of 550-600 m\textsuperscript{2}/g, the surfaces are microporous and exhibit preferential adsorption of phenol from solution.

Palanichamy et al.\textsuperscript{51} investigated adsorption kinetics of phenol controlled burnt wood charcoal system. It has been observed that a stoichometric relationship exists between the adsorbate and adsorbent in the phenol-CBWC system.

Adsorption studies of phenols and their removal using granular activated carbon has been reported by Juric et al.\textsuperscript{52} and McMams et al.\textsuperscript{53}. Removal of p-nitrophenol using activated carbon was reported by Wolborska et al.\textsuperscript{54}.

Paprowicz\textsuperscript{55} et al. and other\textsuperscript{56-58} have utilized activated carbon for the removal of phenolic compounds: phenol, resorcinol, o-chlorophenol, catechol and pyrogallol. The effect of pH, concentration and contact time are reported.
Competitive removal of phenol and 2,4-dichlorophenol in biological activated carbon (BAC) system has been reported by S.R. Ha and S.Vinitnantharat\textsuperscript{59}. The adsorption experiment showed that 2,4-DCP was a stronger adsorbate than phenol, both in single and bisolute system.

Adsorption, desorption, and bioregeneration in an aerobic granular activated carbon reactor for the removal of phenol has been reported by B.R. Kim et al\textsuperscript{60}.

Adsorption-removal of cresol by granular activated carbon for medical wastewater treatment has been reported by Tanada et al\textsuperscript{61}.

Zagorski et al.\textsuperscript{62} have studied equilibria of adsorption of phenols by granular activated carbon. Adsorption behaviour of dihydric phenol-hydroquinone and dihydric phenol-catechol from aqueous solution on activated carbon of industrial and laboratory grade has been investigated in a batch reactor\textsuperscript{63,64}. The adsorption is pH dependent, with a maximum adsorption range between 3-5. The rate controlling step is mainly intraparticle diffusion, although a small boundary layer resistance is experienced.

Experimental investigations were conducted by S.H.Lin and M.J. Cheng on the adsorption characteristics of phenol and m-chlorophenol by organobentonites\textsuperscript{65}. The organobentonites were prepared by modifying the nature of bentonite by various quaternary amines. The empirical Freundlich isotherm was found to describe well the equilibrium adsorption data.
F. Cadina\(^6\) has utilized bentonite for selective removal of organic pollutants. Adsorption of pentachlorophenol by organoclays has been studied by S.A. Boyd et al\(^6\).

Viraraghavan et al.\(^6\) examined the effectiveness of less expensive adsorbents such as peat, fly ash and bentonite in removing phenol from wastewater by adsorption. Results of the study showed that peat, fly ash and bentonite removed phenols from wastewater by adsorption to the extent of 40-45\% when contacted for a period of 16, 5, and 16 h respectively in the pH range of 4 to 5.

Sorption of the organic pollutants phenol, 2,4,5-trichlorophenol and tannic acid onto montmorillonite-based sorbents was studied by Dental et al\(^6\). The sorbents were homoionic Na-or Ca-montmorillonite. Montmorillonite completely exchanged with the cationic organic surfactants dimethyldistearylammonium chloride (or DDA-M) and DDA-M partially reexchanged with Ca\(^2+\)(CA-DDA-M). The sorption capacity for phenol, trichlorophenol and tannic acid was significantly enhanced by surfactant treatment.

A.S. Boyd\(^7\) has performed adsorption studies of substituted phenols on soil.

Adsorption of selected phenol derivatives by dolamite has been reported by Hudson-Baruth et al\(^7\).

Isaction and Frink\(^7\) have studied the nonreversible sorption of phenolic compounds by sediment fractions.
Laquer and Manahan\textsuperscript{73} have studied sorption factors affecting to adsorption of phenol onto silt stone.

Sorption of chlorinated phenols by natural sediments and aquifer materials has been reported by Shellenberg et al\textsuperscript{71}.

Sorption characteristics of some phenol and phenolic effluents on sodium and TEBA-montmorillonite have been determined by Ray and Ram\textsuperscript{75}. It was observed that substituted phenols are better adsorbed than other. TEBA-clay is found better adsorbent than sodium montmorillonite clay due to an expansion in C-dimension.

Sorption of phenol, p-nitriphenol and aniline to ducation organobentonites synthesized by replacing the metal ion in bentonite with both long-chain alkyl quaternary ammonium cations, such as dodecyltrimethylammonium (DDTMA), benzyl dimethyltetradecylammonium (BDTDA), cetyltrimethylammonium (CTMA), octadecyltrimethylammonium (OCTMA), and short-chain alkyl quaternary ammonium cations, such as tetramethyl ammonium (TMA) from water has been reported by L.Zhu et al\textsuperscript{76}. The sorption properties are affected by treatment conditions, such as pH, amount of organobentonite, and shaking time; structure of bentonites, such as interlayer spacing and organic carbon contents and the properties of organic compounds such as solubility and octanol-water coefficient partition.
P. M. Buechler utilized modified bentonites for the removal of phenols from aqueous solution.

Many researchers utilize fly ash for the removal of phenolic compounds.

B.K. Singh et al. have reported flyash and impregnated fly ash for removal of phenols such phenol, o-cresol, m-cresol, o-nitrophenol, and m-nitrophenol from aqueous solutions. The removal mechanism of phenols is explained due to chemical coagulation with metallic oxides. Impregnated fly ash has shown better efficiency of phenol removal than fly ash.

Removal of organic pollutants from wastewaters of coaltar processing industry using activated carbon and fly ash has been studied by N.M. Daci et al.

Severtson et al. have conducted batch sorption experiments for the retention of 2,4-dichlorophenol and 2,4,5-trichlorophenol by pulped wood fibers. The sorption seems to be governed by the interaction of the acid form of these compounds with lignin. Effects of various parameters affecting the adsorption and desorption of phenol on lake sediments from retting and nonretting zones, such as time of equilibrium, pH, ionic strength, temperature etc. has been determined by A. Madhukumar and T.S. Anirudhan.

Coke dust has been used by D. Aifred et al. for the adsorption of multivalent phenols from wastewater.
Srivastva et al.\textsuperscript{87} have utilized local fertilizer waste slurry for the removal of 2,4-dinitrophenol from aqueous solution.

Removal of substituted phenols by low cost carbonaceous adsorbents has been reported by Srivastava et al\textsuperscript{88}.

Sorption and desorption behaviour of 2,4-dichlorophenol by marine sediments has been reported by Fytianos et al\textsuperscript{138}.

Use of fractional design of experiments in the determination of adsorption equilibrium constants: Phenol on activated charcoals has been studied by Annadurai et al\textsuperscript{139}.

**Separation of Phenols**

Petronio et al. have studied adsorption and separation of 2-chlorophenol and 2-nitrophenol onto chelating ion-exchanger in iron (III) form\textsuperscript{89}.

The inorganic ion-exchanger such as stannic molybdate\textsuperscript{90}, zinc silicate\textsuperscript{91}, stannic tungstate\textsuperscript{34}, aluminium magnesium metasilicate\textsuperscript{92} and ion-exchange resins\textsuperscript{93,94} have been reported for the separation of phenolic compounds.

A new adsorbent iron (III) diethanolamine\textsuperscript{21} has been utilized for the chromatographic separation of phenols. Qualitative separation of phenols on impregnated papers and quantitative separation on columns of iron (III) diethanolamine have been achieved.
The high sorption capacity of zinc silicate in Fe(III) form has been utilized for the separation of phenolic compounds. On the basis of difference in Kd values, some analytically important binary and ternary separations on the columns of zinc silicate in Fe (III) form have been achieved.

Rawat et al. have studied alumina in Fe (III) form as a ligand ion-exchanger for the adsorption, separation and recovery of various phenolic compounds.

Singh et al. have reported high sorption capacity of iron hexamine for different phenols (21-92 mg/g). The adsorbent was found to be selective for pyrogallol, pyrocatechol, salicylic acid and tannic acid. Quantitative separation of phenols in the mixture of analytical interest were achieved on the columns of the adsorbent.

**Removal of Dyes**

Activated carbon is the most widely used adsorbent for removal of dyes from wastewaters. The adsorption of basic yellow dye on activated carbon from aqueous solutions under a centrifugal field was explored and interpreted by both pseudo first order mechanism and intraparticle diffusion mechanism. It was concluded that better mass transfer could be provided with centrifugal force. Mckay and Paprowicz and Slodczyk have reported effective decolourization of dye wastewater by granular activated carbon. Colour removal from dye wastewater
by adsorption using powdered activated carbon has been reported by Yeh et al\textsuperscript{100}. 

Adsorption of dyestuffs from aqueous solutions using activated carbon: equilibrium and batch contact time studies were reported by G. Mckay\textsuperscript{101}.

Removal efficiency of activated carbon Filtrasorb 400 (F-400) towards remazol reactive yellow, Ramazol reactive black and ramazol reactive red have been reported\textsuperscript{102}. The adsorption capacity data showed a high removal ability for three reactive dyes and a distinguished ability for R.Yellow. The adsorption capacities for F-400 were attributed to the position surface charge during the adsorption process.

Mitchell et al.\textsuperscript{103} prepared activated carbon from agricultural, municipal, and industrial wastes and studied adsorption of textile dyes.

Adsorption of the adsorbate depends upon various factors such as temperature, pH, concentration, particle size of the adsorbent etc. Dejohn\textsuperscript{104} have studied factors to consider when treating dye wastewater with granular activated carbon to achieve maximum adsorption.

Mittal et al.\textsuperscript{105,106} have used sulphonated coal as an adsorbent for the removal of dyes from wastewater.

Mckay et al.\textsuperscript{107,108} have utilized silica for the removal of colour from effluents. Basic dyes removal from wastewater by
silica has been reported by Ahmed and Ram\textsuperscript{109}.

Alexander et al.\textsuperscript{110} have reported that basic dyes are frequently adsorbed onto silica gel.

Poots et al.\textsuperscript{111} have shown wood as a low cost and effective adsorbent for the removal of basic dyes from wastewater.

The ability of wood to adsorb telon blue (acid blue 25) has been investigated by Poots et al\textsuperscript{112}. The results show that acid dye adsorption on wood is quite successful, although long contact time is required to reach equilibrium.

Equilibrium studies on adsorption of basic dyes on hard wood were carried out by Asfour et al\textsuperscript{113}. They have also reported hard wood saw dust\textsuperscript{114} as an effective adsorbent for colour removal from textile effluents.

Multi component sorption of basic dyes\textsuperscript{115} and adsorption of acid dyes\textsuperscript{116} on peat from aqueous solution are reported.

McKay and Allen have studied surface mass transfer processes for dyestuffs\textsuperscript{117} and pore diffusion model\textsuperscript{118} for dye adsorption onto peat as an adsorbent in batch adsorbers. Chemically treated modified peat has been studied as an economical means of dye water treatment by E.F. Smith et al\textsuperscript{119}.

Batch experiments were conducted to assess the potential use of rice husk as an adsorbent for the removal of methylene
blue from the aqueous solution by A. Lodha et al. The equilibrium isotherm was determined and plotted to obtain the Langmuir, Freundlich and Redlich Peterson constants.

Namita Deo and Manzoor Ali have reported Paddy straw as a low cost adsorbent for the removal of cango red from dilute aqueous solution. The adsorption capacity was found to be increasing uniformly with increasing dose of adsorbent and the process follows the related isothermal laws. The adsorption of the dye on the adsorbent was found to be temperature dependent.

The adsorption of two basic dye stuffs astrazon blue and maxilon red) and two acid dye stuffs (telon blue and erionly red) onto maize cob has been studied by M.S. El-Geundi and 94.5 mg/l adsorption capacities of maize cob for astrazone blue and Maxilon red respectively are reported.

M.M. Nassar and M.S. El-Geundi have used a number of low cost materials (natural clay, bagasse pith and maize cob) as adsorbents for dye stuffs (astrazon blue, maxilon red and telon blue) in aqueous solutions. The relative costs of dye removal were reported to be based on adsorption capacity only. In laboratory scale studies, the results show that carbon has the highest adsorption capacity for dye stuffs in all the systems studied. However, an economic model indicated that natural clay, bagasse pith and maize cob may be economically attractive for the removal of dye stuffs from aqueous solutions.
Gupta et al.\textsuperscript{124} have performed adsorption studies on the removal of chrome dye from aqueous solutions by mixed adsorbent fly ash and coal. Intraparticle diffusion of basic dyes driving during adsorption onto sphagnum peat was studied by Allen\textsuperscript{125} et al. Allen et al.\textsuperscript{126} have also studied the equilibrium adsorption isotherms for basic dye onto lignite.

Boiler bottom ash has been reported for the removal of basic dyes from wastewater by Mall and Upadhyay\textsuperscript{127}. The experimental results show that bottom ash is suitable adsorbent for removal of methylene blue and malachite green. Removal of 100 percent dye is possible in the lower concentration range.

R.Y. Yeh et al. have reported a comparative study of adsorption capacity of various adsorbents for treating dye wastewater\textsuperscript{128}.

A critical review of technology for removing colour from dye house wastewater has been presented by P. Cooper\textsuperscript{129}.

G. Sekran\textsuperscript{130} utilized leather industry solid waste for removal of dye from aqueous solution. The removal of victoria blue from aqueous solution by fly ash was studied by S.K. Khare et al\textsuperscript{131}.

Biosorption of basic dyes by Water Hyacinth roots has been studied by K.S. Low et al\textsuperscript{132}. Sorption studies of basic dyes on Hydrilla verticillata has also been reported by K.S. Low et al\textsuperscript{133}.
Morais et al.\textsuperscript{134} attempted to solve the pollution problem caused by the presence of reactive dye in textile effluent using eucalyptus bark, an abundantly available adsorbent. Parallel adsorption tests under similar conditions, carried out with a commercial activated carbon and with eucalyptus bark, showed for the last one adsorption capacity is about half of that of the first one.

Although activated carbon is generally used for treatment but a variety of other materials have also been used. Basic dyes have been shown to be adsorbed onto fuller's earth by Thornton and Moore\textsuperscript{135}. Dyes are also adsorbed by activated alumina\textsuperscript{136} and Clay\textsuperscript{137}. Adsorption of methylene blue on low cost adsorbents developed from sawdust has been reported by De and Basu\textsuperscript{140}.

Preparation of activated carbons from bamboo and their adsorption abilities for dyes have been reported by Wu, Tseng and Juang\textsuperscript{141}.

Various adsorbents and their adsorption characteristics for different phenols and dyes are summerized in Table 2.1 and 2.2, respectively.
**TABLE 2.1**

List of Adsorbents and Their Adsorbent Characteristics for Different Phenols

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Adsorbent</th>
<th>Selectivity</th>
<th>Operating Conditions</th>
<th>Adsorption/Removal</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Conventional</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(A) Organic Ion-Exchangers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Dowex 50 W-X8</td>
<td>Phenol, p-Cresol</td>
<td>Column</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>Amberlite-XAD</td>
<td>Phenol, p-Nitrophenol, p-Chlorophenol</td>
<td>—</td>
<td>—</td>
<td>2, 8, 13</td>
</tr>
<tr>
<td>3.</td>
<td>Polymeric Adsorbents</td>
<td>Phenols</td>
<td>—</td>
<td>—</td>
<td>3</td>
</tr>
<tr>
<td>4.</td>
<td>Dowex 1 X4</td>
<td>Phenol</td>
<td>Column</td>
<td>—</td>
<td>4</td>
</tr>
<tr>
<td>5.</td>
<td>Porous polymer based on Acrylic Matrix</td>
<td>Phenol, p-Nitrophenol, m-Aminophenol</td>
<td>Batch, 100mg/l</td>
<td>mg/g</td>
<td>5</td>
</tr>
<tr>
<td>6.</td>
<td>Macroreticular Resin</td>
<td>Phenols</td>
<td>—</td>
<td>—</td>
<td>6</td>
</tr>
<tr>
<td>7.</td>
<td>Weakly Basic Anion-Exchanger</td>
<td>Phenols</td>
<td>—</td>
<td>—</td>
<td>7</td>
</tr>
<tr>
<td>8.</td>
<td>Anion-Exchange Resin</td>
<td>Phenols</td>
<td>—</td>
<td>—</td>
<td>9-12, 16,17</td>
</tr>
<tr>
<td>9.</td>
<td>Vinylpyridine Divinyl Benzene Copolymer</td>
<td>Phenols</td>
<td>—</td>
<td>—</td>
<td>14</td>
</tr>
<tr>
<td>10.</td>
<td>Tributyl phosphate and Trialkyl Phosphine Oxide Containing Resins.</td>
<td>Phenol</td>
<td>—</td>
<td>—</td>
<td>15</td>
</tr>
<tr>
<td>11.</td>
<td>Chelating Ion-Exchanger in Fe (III) form</td>
<td>Chlorophenols, Nitrophenols</td>
<td>Column, Conc. =100mg/l</td>
<td>Recovery = 28-100%</td>
<td>89</td>
</tr>
</tbody>
</table>
(B) Inorganic Ion-Exchangers

<table>
<thead>
<tr>
<th></th>
<th>Name</th>
<th>Phenols</th>
<th>Column/Method</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Stannic Molybdate</td>
<td>Phenols</td>
<td>Column</td>
<td>—</td>
</tr>
<tr>
<td>13</td>
<td>Zinc Silicate</td>
<td>m-,p-Cresol, 4-Chlorophenol 0-Nitrophenol</td>
<td>Impregnated paper</td>
<td>91</td>
</tr>
<tr>
<td>13</td>
<td>Stannic Tungstates</td>
<td>Phenols</td>
<td>TLC</td>
<td>34</td>
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<tr>
<td>14</td>
<td>Aluminium Magnesium Metasilicate</td>
<td>Phenols</td>
<td>Batch</td>
<td>92</td>
</tr>
<tr>
<td>15</td>
<td>Ion-Exchange Resins</td>
<td>Phenols</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>16</td>
<td>Iron(III) Diethanol Amine</td>
<td>Pyrogallol, Catechol, Resorcinol Quinol</td>
<td>Column, Conc.=1mg/ml</td>
<td>21</td>
</tr>
<tr>
<td>17</td>
<td>Zinc Silicate in Fe(III) form</td>
<td>Pyrogallol, Catechol, o-Cresol Phenol</td>
<td>Column, Conc.=1mg/ml</td>
<td>95</td>
</tr>
<tr>
<td>18</td>
<td>Alumina in Fe(III) from</td>
<td>Phenol, Resorcinol, o-Chlorophenol, Catechol, Pyrogallol</td>
<td>Column, Conc=1mg/ml</td>
<td>96</td>
</tr>
<tr>
<td>19</td>
<td>Iron(III)Hexamine</td>
<td>Resorcinol, Quinol, Phloroglucinol Salicylic Acid, Pyrocatechol, Pyrogallol</td>
<td>Column</td>
<td>21-92mg/g</td>
</tr>
</tbody>
</table>

(c) Activated Carbons

<table>
<thead>
<tr>
<th></th>
<th>Name</th>
<th>Phenols</th>
<th>Column/Method</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Activated Carbon Filtrasorb-400</td>
<td>Phenol, p-Chlorophenol</td>
<td>—</td>
<td>210,400 mg/g</td>
</tr>
<tr>
<td>21</td>
<td>Activated Carbon</td>
<td>Phenols and Substituted Phenols</td>
<td>—</td>
<td>38,40, 41,42, 45,47, 54,58, 63,64.</td>
</tr>
<tr>
<td></td>
<td>Activated Carbon from Straw and used Rubber Tyres</td>
<td>Phenol, p-Chlorophenol</td>
<td>Column, Conc.=6.03 mmol/l</td>
<td>2.08 m mol/g</td>
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<tr>
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<td>-----------------------------------------------</td>
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<tr>
<td>23.</td>
<td>Activated Carbon from Apricot Stone Shell</td>
<td>2,4-Dinitro and 2,4-Dichloro-Phenols</td>
<td>Batch, Conc.=10mg/l</td>
<td>63-65%</td>
</tr>
<tr>
<td>24.</td>
<td>Activated Carbon from Agricultural Raw Materials and Spanish Lignites</td>
<td>Chlorophenols</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>25.</td>
<td>Activated Carbon from Fertilizer Waste Slurry</td>
<td>4 Nitrophenol, 2,4,6-Trinitrophenol, 4-Chlorophenol, 1,3- Dihydroxybenzene</td>
<td>Batch</td>
<td>—</td>
</tr>
<tr>
<td>26.</td>
<td>Activated Carbon Cloth from Jute Fibre.</td>
<td>Phenol</td>
<td>—</td>
<td>—</td>
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<tr>
<td>27.</td>
<td>Granular Activated Carbon</td>
<td>Phenol</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>28.</td>
<td>Activated Decolour-ring Charcoal</td>
<td>Phenol</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>29.</td>
<td>Biological Activated Carbon</td>
<td>Phenol, 2,4-Dichlorophenol</td>
<td>Batch</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td><strong>Non-Conventional</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30.</td>
<td>Organobentonite</td>
<td>Phenol, m-Chlorophenol</td>
<td>Batch, Conc.=100mg/l</td>
<td>80%, 12h</td>
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<tr>
<td>31.</td>
<td>Organoclay</td>
<td>p-Chlorophenol</td>
<td>—</td>
<td>—</td>
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<tr>
<td>32.</td>
<td>Montmorillonite Based Sorbents</td>
<td>Phenol,2,4,5, Trichlorophenol, Tannic acid</td>
<td>Batch</td>
<td>—</td>
</tr>
<tr>
<td>33.</td>
<td>Peat, Fly ash, and Bentonite</td>
<td>Phenol</td>
<td>Batch, Conc.=1mg/l</td>
<td>42-45%</td>
</tr>
<tr>
<td>34.</td>
<td>Soil</td>
<td>Substituted phenols</td>
<td>—</td>
<td>—</td>
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<tr>
<td>35.</td>
<td>Dolamite</td>
<td>Phenols</td>
<td>—</td>
<td>—</td>
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<tr>
<td>36.</td>
<td>Sediment Fractions</td>
<td>Phenols</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>37.</td>
<td>Silt Stone</td>
<td>Phenols</td>
<td>—</td>
<td>—</td>
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<tr>
<td></td>
<td>Description</td>
<td>Phenol Type</td>
<td>Batch/Concentration</td>
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</tr>
<tr>
<td>---</td>
<td>-----------------------------------------------------------------------------</td>
<td>------------------------------------</td>
<td>---------------------</td>
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</tr>
<tr>
<td>38.</td>
<td>Aquifer Material and Natural Sediments</td>
<td>Chlorinated Phenols</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>39.</td>
<td>Na and Montmorillonite</td>
<td>Phenol, m-cresol, m-Nitrophenol, p-Bromophenol</td>
<td>29.48-109.4mg/g</td>
<td></td>
</tr>
<tr>
<td>40.</td>
<td>Dual Cation Organobentonites</td>
<td>Phenol and p-Nitrophenol</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>41.</td>
<td>Modified Bentonites</td>
<td>Phenols</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>42.</td>
<td>Flyash</td>
<td>Phenols</td>
<td>78-81</td>
<td></td>
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<tr>
<td>42.</td>
<td>Impregnated Flyash</td>
<td>Phenols, o- and m-Cresol, o- and m-Nitrophenol</td>
<td>13.46%</td>
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<tr>
<td>43.</td>
<td>Activated Carbon, Flyash</td>
<td>Phenol</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>44.</td>
<td>Pulped Wood Fibre</td>
<td>2,4-Dichlorophenol 2,4,5-Trichlorophenol</td>
<td>—</td>
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<tr>
<td>45.</td>
<td>Lake Sediments</td>
<td>Phenols</td>
<td>—</td>
<td></td>
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<tr>
<td>46.</td>
<td>Coke dust</td>
<td>Phenols</td>
<td>—</td>
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<td>47.</td>
<td>Fertilizer Waste Slurry</td>
<td>2,4-Dinitrophenol</td>
<td>—</td>
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<tr>
<td>48.</td>
<td>Low cost Carbonaceous Adsorbent</td>
<td>2,4,6-Trinitrophenol, 4-Nitrophenol, 4-Chlorophenol, 1,3-Dihydroxy benzene</td>
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</tr>
<tr>
<td>49.</td>
<td>Chemically Treated Saw dust</td>
<td>Pyrogallol, Pyrocatechol</td>
<td>28 and 52 mg/l</td>
<td></td>
</tr>
<tr>
<td>50.</td>
<td>Iron(III)Hydroxide Loaded Marble</td>
<td>Pyrogallol, Pyrocatechol</td>
<td>9.10 mg/g</td>
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<tr>
<td>Sl. No.</td>
<td>Adsorbent Description</td>
<td>Selectivity</td>
<td>Operating Conditions</td>
<td>Adsorption/Removal</td>
</tr>
<tr>
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</tr>
<tr>
<td>1.</td>
<td>Activated Carbon</td>
<td>Basic Yellow Dye</td>
<td>Batch</td>
<td>Con.= 205mg/l</td>
</tr>
<tr>
<td>2.</td>
<td>Activated Carbon</td>
<td>Dye stuff</td>
<td>—</td>
<td>—</td>
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<td>3.</td>
<td>Activated Carbon from Agricultural, Municipal and Industrial Waste</td>
<td>Textile Dyes</td>
<td>—</td>
<td>—</td>
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<td>5.</td>
<td>Powdered Activated Carbon</td>
<td>Dye Wastewater</td>
<td>—</td>
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<td>6.</td>
<td>Activated Carbon Filtrasorb-400</td>
<td>Remazol Reactive-yellow, Black and Red</td>
<td>—</td>
<td>—</td>
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<tr>
<td>7.</td>
<td>Sulphonated Coal</td>
<td>Dyes</td>
<td>—</td>
<td>—</td>
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<tr>
<td>8.</td>
<td>Silica Gel</td>
<td>Basic Dyes</td>
<td>—</td>
<td>—</td>
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<tr>
<td>9.</td>
<td>Wood</td>
<td>Basic Dyes</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>10.</td>
<td>Wood</td>
<td>Acid Dyes</td>
<td>—</td>
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</table>

**TABLE 2.2**

List of Adsorbents and Their Adsorbent Characteristics for Dyes
<table>
<thead>
<tr>
<th>No.</th>
<th>Source/Type</th>
<th>Dye Type</th>
<th>Batch</th>
<th>Concentration</th>
<th>Page</th>
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<tbody>
<tr>
<td>11</td>
<td>Hard Wood Basic Dyes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>113</td>
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<tr>
<td>12</td>
<td>Hard Wood Textile Dyes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>114</td>
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<td>13</td>
<td>Saw dust Peat Basic Dyes</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>14</td>
<td>Peat Acid Dyes</td>
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<td>-</td>
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<tr>
<td>15</td>
<td>Peat Dyestuff</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>117,118</td>
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<tr>
<td>16</td>
<td>Chemically Treated Modified Peat</td>
<td>Dyes</td>
<td>-</td>
<td>-</td>
<td>119</td>
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<tr>
<td>17</td>
<td>Silica Dyes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>107-109</td>
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<tr>
<td>18</td>
<td>Rice Husk Methylene Blue</td>
<td>Batch</td>
<td>0.104mg/g</td>
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<td>19</td>
<td>Paddy Straw Congo Red</td>
<td>Batch</td>
<td>10mg/g</td>
<td>400mg/l</td>
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<td>20</td>
<td>Maize cob Astrazon Blue, Maxilon Red, Telon Blue, Aerionyl Red</td>
<td>Batch</td>
<td>41-160mg/g</td>
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<tr>
<td>21</td>
<td>Natural clay, Bagasse pith, and Maize cob</td>
<td>Astrazon Blue, Maxilon Red, Telon Blue</td>
<td>Batch</td>
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<td>123</td>
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<td>22</td>
<td>Flyash + Coal Chrome Dye</td>
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<td>-</td>
<td>124</td>
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<td>23</td>
<td>Sphagnum Peat Basic Dyes</td>
<td>Batch</td>
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<td>24</td>
<td>Lignite Basic Dyes</td>
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<td>25</td>
<td>Boiller Bottom Ash Methylene Blue, Malachte Green</td>
<td>Batch</td>
<td>95-100%</td>
<td>Conc.= 10-40 mg/l</td>
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<td>Leather Industry Solid Waste Dyes</td>
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<td>-</td>
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<td>Name</td>
<td>Type</td>
<td>Notes</td>
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<td>27</td>
<td>Fly Ash</td>
<td>Victoria Blue</td>
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<td>28</td>
<td>Water Hyacinth Roots</td>
<td>Basic Dyes</td>
<td>—</td>
<td>132</td>
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<td>29</td>
<td>Hydrilla Verticillata</td>
<td>Basic Dyes</td>
<td>—</td>
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<td>30</td>
<td>Eucalyptus Bark</td>
<td>Reactive Dyes</td>
<td>Batch</td>
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<td>31</td>
<td>Fuller's Earth Alumina</td>
<td>Basic Dyes</td>
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<td>32</td>
<td>Activated Alumina</td>
<td>Dyes</td>
<td>—</td>
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<tr>
<td>33</td>
<td>Clay</td>
<td>Dyes</td>
<td>—</td>
<td>137</td>
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<tr>
<td>34</td>
<td>Synthetic Polymer</td>
<td>Dyes</td>
<td>—</td>
<td>138</td>
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<tr>
<td>35</td>
<td>Chemically Treated Psidium Guyava Leaves</td>
<td>Methylene Blue Malachite Green Crystal Violet Safranine</td>
<td>Batch</td>
<td>138</td>
<td></td>
</tr>
</tbody>
</table>
REFERENCES

44. F.Caturla, J.M. Martin-Martinez, M.Moling Sabio, F. Rodriguez-


