

**ECO - FRIENDLY LOW COST ADSORBENTS USED FOR THE  
REMOVAL OF CRYSTAL VIOLET DYE – A REVIEW**

**UMAMAHESWARI.K**

**20PCH025**

**Thesis submitted to**

**Avinashilingam Institute for Home Science and Higher Education for Women**

**Coimbatore – 641043**

**In Partial fulfillment of the Requirements for the Degree of**

**MASTER OF SCIENCE IN CHEMISTRY**

**May – 2022**

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*N. Renugadevi*  
26/05/2022

**Signature of the**

**Supervisor**

*Rasmita*  
26/5/2022

**Signature of the**

**Head of the Department**



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## INTRODUCTION

### POLLUTION

Introduction of contaminants into the natural environment that causes adverse change in the environment is known as pollution. These harmful substances are called pollutants. Pollutants can be natural such as volcanic ash or created by human activity such as trash or run off produced by factories.

### MAJOR TYPES OF POLLUTION

- ✧ Air Pollution
- ✧ Land Pollution
- ✧ Water Pollution
- ✧ Noise Pollution
- ✧ Radioactive Pollution

### AIR POLLUTION

- ✧ Air pollution refers to the release of pollutants into the air that are detrimental to human health and the planet as a whole.
- ✧ The pollutants can be solid particles, liquid droplets or gases.

Pollutants are of two types,

- ✧ Primary pollutants
- ✧ Secondary pollutants



Primary pollutants usually produced by processes such as ash from a volcanic eruption.

### **PRIMARY POLLUTANTS**

<b>POLLUTANTS</b>	<b>HEALTH EFFECTS AT HIGH LEVEL</b>
Nitrogen oxide, Sulphur dioxide	These gases irritate the airways of the lungs, increasing the symptoms of those lung diseases.
Carbon dioxide	This gas causes headaches, dizziness, difficulty in breathing, sweating, increasing heart rate, elevated blood pressure, etc....
Carbon monoxide	This gas prevents the uptake of oxygen by the blood. This can lead to significant reduction in the supply of oxygen to the heart, particularly in people suffering from heart disease.
Chlorofluorocarbon	Cause dizziness, loss of concentration, central nervous system depression and arrhythmia.

## SECONDARY POLLUTANTS

POLLUTANTS	HEALTH EFFECTS
Smog and soot	They can penetrate the lungs and bloodstream and worsen bronchitis, lead to heart attacks and even hasten death.
Benzene	It is a carcinogen and can cause eye, skin and lung irritation and blood disorders
Dioxins	Affects the liver and harms the immune, nervous and endocrine systems as well as reproductive function.
Lead	It can damage children's brains and kidney in humans
Poly cyclic aromatic hydrocarbons	It can cause eye and lung irritation and cancer.
Mold	Mold exposure can precipitate asthma attacks, an allergic response and even they produce toxins that would be dangerous for anyone to inhale.
Pollen	Accelerated aging of the lungs, Loss of lung capacity and reduce lung function. Diseases like asthma, bronchitis, emphysema and possibly cancer.

## **WATER POLLUTION**

Water pollution is the contamination of water bodies with undesirable substances which make it unfit for usage, usually as a result of human activities and due to the discharge of industrial effluent into water bodies without proper treatment. Water bodies include lakes, rivers, oceans, aquifers and groundwater.

### **CAUSES FOR WATER POLLUTION**

- ✧ Urbanization
- ✧ Deforestation
- ✧ Damming of rivers
- ✧ Destruction of Wetlands
- ✧ Industries
- ✧ Agriculture
- ✧ Accidental water pollution

### **WATER POLLUTION DUE TO DYES**

- ✧ The textile industry consumes a substantial amount of water in its manufacturing processes used mainly in the dyeing and finishing operations of the plants.
- ✧ The waste water from textile plants is classified as the most polluting of all the industry sectors, considering the volume generated as well as the effluent composition.
- ✧ Dyes can remain in the environment for an extended period of time, because of high thermal and photo stability and to resist bio degradation.

### **EFFECTS OF WATER POLLUTION**

- ✧ Human health gets affected
- ✧ Contamination of the food chain
- ✧ Death of aquatic animals
- ✧ Infant Mortality
- ✧ Lack of portable water



## **LAND POLLUTION**

The deposition of solid or liquid waste materials on land or underground in a manner that can contaminate the soil and groundwater, threaten public health and cause unsightly conditions and nuisances.

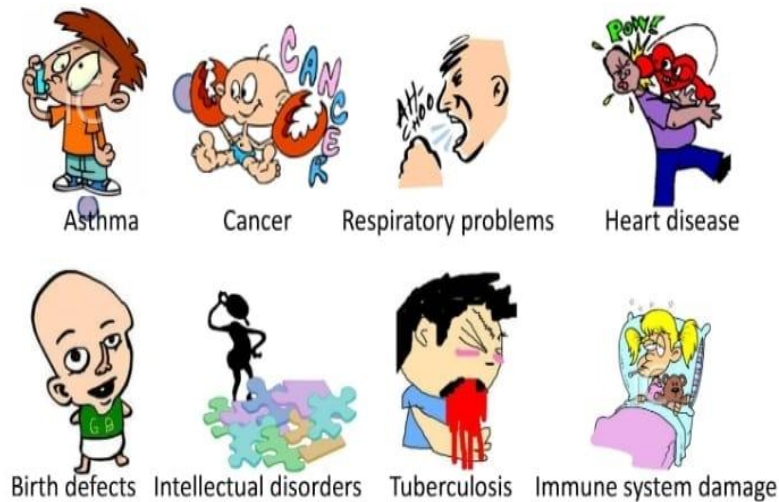
### **CAUSES OF LAND POLLUTION**

- ✧ Deforestation
- ✧ Agriculture
- ✧ Industry
- ✧ Mining
- ✧ Landfills waste



## EFFECTS OF LAND POLLUTION

- ✧ Human health affected
- ✧ Increase in landfills sites
- ✧ Soil pollution
- ✧ Air pollution
- ✧ Water pollution
- ✧ Environmental degradation
- ✧ Wildlife affected



## NOISE POLLUTION

- ✧ Noise pollution takes place when there is either an excessive amount of noise or an unpleasant sound that causes a temporary disruption in the natural balance.
- ✧ Noise is measured in Decibel (dB).The average noise level of 97.60 dB Obtained exceeded the WHO value of 50 Db allowed for residential areas.

## CAUSES OF NOISE POLLUTION

- ✧ Industrialization
- ✧ Poor urban planning
- ✧ Social events
- ✧ Transportation and Construction activities
- ✧ Household chores



## **EFFECTS OF NOISE POLLUTION**

- ✧ Hearing problems
- ✧ Health issues
- ✧ Sleeping disorders
- ✧ Cardiovascular issues
- ✧ Trouble communicating
- ✧ Wildlife gets affected.



## **RADIOACTIVE POLLUTION**

- ✧ Radioactive pollution occurs when there is presence or depositions of radioactive materials in the atmosphere or environment threat due to radioactive decay
- ✧ The destruction caused by the radioactive materials is because of the emissions of hazardous ionizing radiation like alpha (or) beta (or) gamma rays or particles like neutrons in the environment

## **CAUSES OF RADIOACTIVE POLLUTION**

- ✧ Nuclear accidents from nuclear energy generation plants
- ✧ The use of nuclear weapons as Weapon Mass Destruction (WMD)
- ✧ Use of radioisotopes
- ✧ Mining
- ✧ Spillage of radioactive chemicals
- ✧ Test on radiation
- ✧ Cosmic rays



## **EFFECTS OF RADIOACTIVE POLLUTION**

- ✧ Genetic mutation occurs.
- ✧ Soil infertility
- ✧ Cell destruction occurs in animals and human



## **DYE POLLUTION**

- ✧ Dye pollution in the textile industry is a little known but a damaging by-product of clothes manufacturing. Drinking water sources are being contaminated, canals and rivers are polluted, and surrounding areas are becoming inhabitable because of the adverse effect of the chemicals.
- ✧ Textile, leather, pharmaceutical, polymer & plastic and paper & pulp industries use large amounts of different varieties of dyes and discharge the industrial effluent without proper treatment into water bodies.
- ✧ The dyeing industrial effluent plays a major role in water pollution. Thus the dyes present in the effluent should be treated properly before its discharge into water bodies.



## **DYE REMOVAL METHODS**

Physical methods of dye removal are adsorption, coagulation or flocculation, ion exchange, irradiation, membrane filtration, nano filtration (or) ultra filtration and reverse osmosis.

### **COAGULATION**

- ✧ Coagulation is a process used to neutralize charges and form a gelatinous mass to trap particles thus forming a mass large enough to settle or be filtered from solution.
- ✧ Flocculation is gentle stirring or agitation to encourage the particles thus formed to agglomerate into masses large enough to settle or be filtered from solution.

### **ION EXCHANGE**

Ion exchange is a water treatment method where one or more undesirable ionic contaminants are removed from water by exchange with another non-objectionable or less objectionable ionic substance. Both the contaminant and the exchanged substance must be dissolved and have the same type of electrical charge.

### **ULTRAFILTRATION**

Ultra filtration is a variety of membrane filtration in which forces like pressure or concentration gradients lead to a separation through a semipermeable membrane. Suspended solids and solutes of high molecular weight are retained in the so-called retentate, while water and low molecular weight solutes pass through the membrane in the permeate.

### **REVERSE OSMOSIS**

Reverse osmosis removes contaminants from unfiltered water or feed water, when pressure forces it through a semipermeable membrane. Water flows from the more concentrated side (more contaminants) of the reverse osmosis membrane to the less concentrated side (fewer contaminants) to provide clean drinking water. The fresh water produced is called permeate. The concentrated water left over is called the waste or brine.

## **ADSORPTION**

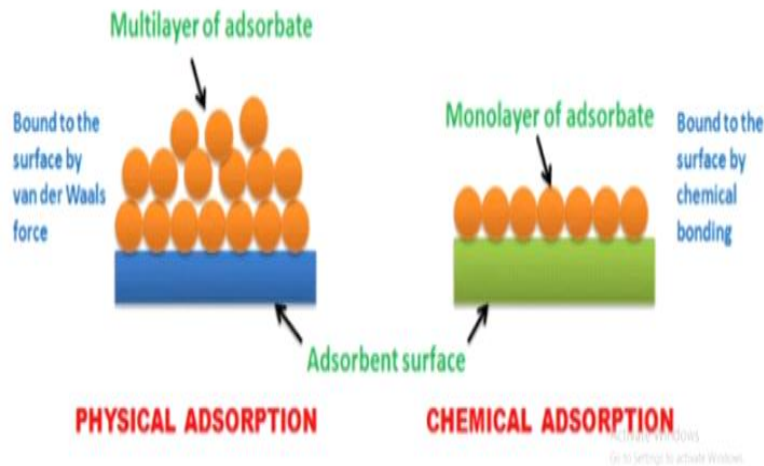
- ✧ The process of adsorption arises due to presence of unbalanced or residual forces at the surface of solid or liquid phase.
- ✧ These unbalanced residual forces have a tendency to attract the molecular species with which it comes in contact with the surface.
- ✧ Adsorption involves two components Adsorbent and Adsorbate.
- ✧ Adsorbent is the substance on the surface of which adsorption takes place.
- ✧ Adsorbate is the substance which is being adsorbed on the surface of adsorbent.  
Adsorbate is being adsorbed.

### **TYPES OF ADSORPTION**

- ✧ Physical adsorption
- ✧ Chemical adsorption
- ✧ Ion exchange adsorption
- ✧ Specific adsorption this type of adsorption purely depends on the attractive forces existing between the adsorbate and the adsorbent.

### **PHYSICAL ADSORPTION**

- ✧ If the forces of attraction existing between adsorbate and adsorbent are Vanderwaals forces, the adsorption is called physical adsorption.
- ✧ It is also known as Vander Waals adsorption.
- ✧ In this adsorption the forces of attraction between the adsorbate and adsorbent are very weak, therefore this type of adsorption can be easily reversed by heating or by decreasing the pressure.



## CHEMICAL ADSORPTION

- ✧ If the forces of attraction existing between adsorbate and adsorbent are almost the same strength as chemical bonds, the adsorption is called chemical adsorption.
- ✧ It is also known as Langmuir adsorption.
- ✧ In this adsorption the forces of attraction are very strong, therefore adsorption cannot be easily reversed.

Though there are many physical methods like coagulation, filtration, ion exchange, reverse osmosis, etc... are available for dye removal from industrial effluent, adsorption is found to be an efficient and as well as an economical method.

## ION EXCHANGE ADSORPTION

- ✧ Electrostatic force of attraction acts between the ionic species of opposite charges at the surface of the adsorbent.
- ✧ In this adsorption characteristic interactions are ion-ion and ion-dipole.

## SPECIFIC ADSORPTION

- ✧ Attachment of adsorbate molecules at functional groups on an adsorbent surface results in specific interaction.
- ✧ But does not lead to adsorbate transformation.

- ✧ Interaction exhibits a range of binding energies associated with lower energy, physical adsorption to the higher energies involved in chemisorptions.

### **HENRY'S LAW RELATED TO ADSORPTION**

- ✧ Henry's law states that adsorbate surface is proportional to the partial pressure of adsorptive gaseous molecules.
- ✧  $P_{\text{gas}}$  - partial pressure of gaseous molecules.
- ✧  $K_H$  - Henry's adsorption constant.
- ✧  $C_{\text{aq}}$  - concentration of aqueous solution

### **CONVENTIONAL ADSORBENT**

- ✧ Activated carbon
- ✧ Silica gel
- ✧ Activated alumina
- ✧ Clay minerals etc...

### **NON CONVENTIONAL ADSORBENT**

- ✧ Adsorbent from industrial and agricultural wastes.
- ✧ Coal Adsorbent
- ✧ Adsorbent from bio- resources etc...



## **Literature Review**

## REVIEW OF LITERATURE

### AGRICULTURAL WASTE ADSORBENTS

- **Milind Ubale *et.al* (2016)** used Green peas shell (GPS) and activated carbon obtained from green peas shell (activated using sulphuric acid) as adsorbents in the removal of crystal violet dye from aqueous solution. The minimum dye removal of crystal violet dye (57.21%) onto the surface of untreated GPS and the maximum of (96.25%) onto the surface of sulphuric acid treated GPS surface obtained in the batch adsorption studies carried out under the following conditions:- adsorbent dosage:1g,crystal violet dye solution concentration :100 ppm , temperature : 60°C contact time : 60 minutes, pH: 7 Langmuir and Freundlich isotherm models described the adsorption of crystal violet dye on GPS.
- **Lairini *et.al* (2017)** prepared activated carbon from potato peel (*solanum tuberosum*) using hydrochloric acid and sodium hydroxide and used as an adsorbent used for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (93.45%) obtained at pH 6 with 1.5g of adsorbent dosage using 200 ppm dye solution concentration in 20 minutes of contact time at 30°C.The adsorption experimental data was fitted by pseudo second order kinetic model.
- **Patil *et.al* (2012)** prepared adsorbent from *Leucaena Leucocephala* (*subabul*) seed pods using sodium hydroxide (0.1N ) and used for the removal of crystal violet dye from aqueous solution .The maximum dye removal efficiency (98%) was achieved at pH 11 and at 50°C in 30 minutes of contact time with 2g adsorbent dosage using 10 ppm concentration of dye solution.Adsorption data better fitted to Langmuir adsorption isotherm.The adsorption process followed pseudo second order kinetic model.

- An activated carbon prepared from oak leaves using phosphoric acid (1:1) used for removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (87.8%) obtained at pH 7 and at 20 minutes of contact time with 30 mg of adsorbent dosage using 100 ppm dye solution concentration at 100°C. The maximum adsorption capacity was found to be 41.15 mg/g (Langmuir adsorption isotherm) and 2.89g/l (Freundlich adsorption isotherm). **Sulyman et.al (2014)**.
  
- **Kulkarni et.al (2017)** investigated the adsorption of crystal violet dye from aqueous solution using water hyacinth plant root as an adsorbent. The maximum dye removal efficiency (88.89%) was achieved at pH 7.8 at 27°C in 120 minutes of contact time with 1g of adsorbent dosage using 500 ppm concentration of dye solution. Adsorption of crystal violet dye followed pseudo second order kinetic model. Thermodynamic analysis of the adsorption of crystal violet dye is spontaneous and endothermic in nature.
  
- **Elsherif et.al (2021)** investigated the removal of crystal violet dye using activated carbon obtained by treating olive leaves powder (OLP) with hydrochloric acid and sodium hydroxide. The maximum dye removal efficiency (87.06%) was achieved at pH 7.5 at 60°C in 24 hours of contact time with 0.1g of adsorbent dosage using 50 ppm dye solution concentration. Langmuir and Freundlich adsorption isotherm models described the adsorption equilibrium. The adsorption of crystal violet dye followed the pseudo second order kinetic model.
  
- **Oloo et.al (2020)** prepared activated carbon from *Rhizophora mucronate stem* barks by treating with sodium chloride and used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (99.8%) obtained in 60 minutes of contact time at pH 7 with 0.5g of adsorbent dosage using 250 ppm dye solution concentration at 25°C, Thus *Rhizophora mucronate stem* barks can be used as a low cost efficacious alternate material for crystal violet dye removal from effluent. The adsorption of crystal violet dye followed pseudo second order kinetic model.

- **Ahmadkhan *et.al* (2021)** used platanus orientalis (*chinar tree*) leaf powder as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (90%) was achieved at pH 6.52 and at 60°C in 40 minutes of contact time with 2.5g of adsorbent dosage using 20 ppm concentration of dye solution. The experimental data revealed that adsorption followed pseudo second order kinetic model. According to Langmuir adsorption isotherm. The maximum adsorption capacity was found to be 25.8mg/gm adsorbent.
- **Umar Yunasa *et.al* (2021)** prepared activated carbon from *Balanites aegyptiaca* seed shell using NaOH (0.1M) and used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (85.29%) obtained at pH 8 with 1.0g of adsorbent dosage using 50 ppm dye solution concentration in 90 minutes of contact time at 30°C. The adsorption kinetics followed pseudo second order rate equation.
- **Lokman Hossain *et.al* (2015)** used Black tea leaves powder (BTL) as an adsorbent in the removal of crystal violet dye. The maximum dye removal efficiency was found to be (15%) was achieved at pH 6 and at 30°C with 0.05g of adsorbent dosage using 25 ppm concentration of dye solution in 6 hours of contact time. The adsorption kinetics followed pseudo second order rate equation and Freundlich adsorption isotherm well described the adsorption data. Adsorption is physical in nature.
- An activated carbon prepared from *Nostoc linckia* using NaOH used as an adsorbent for the removal of crystal violet dye. The maximum dye removal efficiency (90%) obtained at pH 9 with 9.0g of adsorbent dosage using 200 ppm dye solution concentration is 24 hours of contact time at 80°C. The adsorption of crystal violet dye followed pseudo first order kinetic model. [Mona *et.al* (2011)].
- **Zakariyaa Uba Zango *et.al* (2018)** prepared microcrystalline cellulose from groundnut shell and activated using HCl and used as an adsorbent in the removal of crystal violet dye. The maximum dye removal efficiency (62%) was achieved at pH 10 and at 85°C in 30

minutes of contact time with 0.1g of adsorbent dosage using 100 ppm dye solution concentration.

- An activated carbon prepared from pomegranate peels using  $H_3PO_4$  and used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (85%) obtained at pH 11 with 0.1g of adsorbent dosage using 100 ppm dye solution concentration in 60 minutes of contact time at 26°C. The adsorption of crystal violet dye followed pseudo second order kinetic model [Abbas *et.al* (2020)].
- Vanni *et.al* (2017) prepared activated carbon from powdered grape seeds (PGS) using  $HNO_3$  and NaOH and used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (80%) obtained at pH 6.85 and 25°C in 90 minutes of contact time with 2g of adsorbent dosage using 500 ppm dye solution concentration. The adsorption of crystal violet dye was spontaneous favourable and endothermic in nature.
- Sahbaz *et.al* (2015) prepared activated carbon from active sludge using KOH(1:1) and used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (96.2%) obtained at pH 9 with 6g of adsorbent dosage in 150 minutes of contact time using 100 ppm concentration of dye solution at 55°C. The adsorption of kinetic data followed pseudo second order rate equation. The thermodynamic study revealed that adsorption process was spontaneous and endothermic in nature.
- Sudamalla *et.al* (2012) prepared activated carbon from mango kernel using HCl (0.1) and used as an adsorbent for the removal of crystal violet dye. The maximum dye removal efficiency (95%) obtained at pH 9 with 0.075g of adsorbent dosage in 2 hours of contact time using 100 ppm dye solution concentration at 35°C.
- Goksu *et.al* (2017) used activated almond shells as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (79%) obtained at pH 7 with 0.4g of adsorbent dosage in 180 minutes of contact time at 20°C, when the

concentration dye solution is 10 ppm. The experimental data revealed that adsorption followed pseudo second order rate equation. Thermodynamic parameters revealed that the adsorption process was spontaneous and endothermic in nature.

- **Muhammad *et.al* (2012)** obtained activated carbon adsorbent from agro waste (Groundnut shell (GS) and Orange peel (OP)) using HCl and used in the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (98.3%) obtained, under the following optimizing adsorption conditions; adsorbent dosage, 5.0g, crystal violet dye solution concentration 10ppm ; contact time 45 minutes; pH 8 and temperature 80°C.
- **Haliru Aivada Kadir *et.al* (2019)** used activated carbon obtained from corn stalk for the removal of crystal violet dye from aqueous solution .The maximum dye removal efficiency (82%) obtained at pH 8 in 120 minutes of contact time with 0.3g of adsorbent dosage using 50 ppm dye solution concentration at 80°C. The adsorption data fitted well with Freundlich adsorption isotherm .The adsorption process followed pseudo second order kinetic rate equation.
- **Nirban Laskar *et.al* (2017)** used modified Bambusa Tulda activated carbon as an adsorbent for the removal of crystal violet dye from water. The maximum dye removal efficiency (99%) obtained at pH 11 and at 50°C in 30 minutes of contact time with 2g of adsorbent dosage using 10 ppm concentration of dye solution. Adsorption data better fitted to Langmuir adsorption isotherm. The adsorption process followed pseudo second order kinetic model.
- Chenopidium album was used as a low cost adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (89.5%) was achieved at pH 7 and at 25°C with 6mg of adsorbent dosage using 10 ppm concentration of dye solution in 24 hours of contact time. The thermodynamic study revealed that adsorption is endothermic in nature. The adsorption followed pseudo first order kinetic model [**Arora *et.al* (2019)**].
- **Limet *et.al* (2020)** activated tropical wild fern (*Diplazium esculentum*) using NaOH and used as a low cost adsorbent for the removal of crystal violet dye from aqueous solution. The

maximum dye removal efficiency (92.47%) obtained in 180 minutes of contact time at pH 8 with 500mg of adsorbent dosage using 250 ppm dye solution concentration at 70°C. The adsorption kinetics followed the pseudo second order rate equation.

- **Himanshu patel *et.al* (2010)** prepared an activated carbon from tamarind seed powder using HCl (1N) and used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (95%) was achieved at pH 11 and at 60°C in 4 hours of contact time with 5.0g of adsorbent dosage using 500 ppm dye solution concentration. The experimental data well fitted with Langmuir adsorption isotherm model. Adsorption followed pseudo second order kinetic model.
- **Blanco Flores *et.al* (2014)** used vitreous tuff mineral treated with NaOH as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (90%) obtained at pH 5 and at 30°C in 3 hours of contact time with 500mg of adsorbent dosage using 25 ppm dye solution concentration. The adsorption well fitted with both Langmuir and Freundlich adsorption isotherm models. The adsorption kinetics followed pseudo second order rate equation.
- **Saniya *et.al* (2020)** used *Murraya koenigii* stem biochar as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency of the adsorbent used in the study was found to be (98.33%) under the following batch adsorption experimental conditions : adsorbent dosage : 100 mg ; contact time : 60 minutes; pH 6 ; dye solution concentration : 10 ppm and temperature 35°C. The adsorption data best fitted with Langmuir adsorption isotherm model. The adsorption process followed pseudo second order rate equation.
- **Raina Remmani *et.al* (2021)** used Algerian clay as a low value adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency ( $\approx 100\%$ ) obtained at pH 7 and at 60°C in 240 minutes of contact time with 32.8 mg of adsorbent dosage using 20 ppm dye solution concentration. The adsorption followed pseudo second

order kinetic model. The thermodynamic study revealed that adsorption process was spontaneous and exothermic in nature.

- **Mashaal Alshabanat *et.al* (2013)** prepared activated carbon from date palm fiber using NaOH (1M) and used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (89%) was achieved at pH 7 and at 55°C in 150 minutes of contact time using 25 ppm dye solution concentration with 0.25g of adsorbent dosage. The kinetic data fitted to pseudo second order kinetic model. Thermodynamic study revealed that adsorption process was spontaneous and exothermic in nature.
- An activated carbon prepared from *Ricinus communis* pericarp using H<sub>2</sub>SO<sub>4</sub> (50%) used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (≈100%) obtained at pH 7 with 25 mg of adsorbent dosage using 50 ppm dye solution concentration in 12 hours of contact time at 100±5°C. Adsorption followed both Langmuir and Freundlich adsorption isotherm model [**Pattabhi *et.al* (2009)**].
- **Kiplimo *et.al* (2019)** used waste coffee husks as an adsorbent for the removal of crystal violet dye. The maximum dye removal efficiency (98%) obtained at pH 3 and at 60°C with 1.5g of adsorbent dosage using 50 ppm dye solution concentration in 10 minutes of contact time. The adsorption followed pseudo second order kinetic model. The adsorption data well fitted with both Langmuir and Freundlich adsorption isotherm models.
- **Rawat *et.al* (2017)** prepared activated carbon from *mentha piperita* using HCl and H<sub>2</sub>SO<sub>4</sub>(0.1N) and used a low cost adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (90%) obtained at pH 7 and at 80°C in 75 minutes of contact time with 0.1g of adsorbent dosage using 100 ppm dye solution concentration. The adsorption of crystal violet dye followed pseudo second order kinetic model. The thermodynamic study revealed that adsorption is spontaneous and endothermic in nature.

- An activated carbon obtained from rhizomes of black turmeric used for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (99.95%) obtained at pH 9 in 24 hours of contact time with 30 mg of adsorbent dosage using 10 ppm dye solution concentration at 45°C. Thermodynamic study revealed that adsorption process was spontaneous, feasible and endothermic in nature. [Patelet *et al.* (2021)].
- An activated carbon prepared from Granular red mud using NaOH (0.1M) used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (≈100%) obtained at pH 11 and at 65°C in 24 hours of contact time with 2.0g of adsorbent dosage using 600 ppm dye solution concentration. The adsorption process followed pseudo second order kinetic model. [Du *et al.* (2019)].
- **Anamaria Torok *et al.* (2017)** used *Elodea Canadensis* as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (72%) was achieved at pH 7 and at 40°C in 9 days of contact time with 4g of adsorbent dosage using 30 ppm dye solution concentration. The adsorption process followed pseudo second order kinetic model. The adsorption data fitted well with Freundlich adsorption isotherm.
- **Shehata *et al.* (2016)** used *Aspergillus niger* as an adsorbent in the removal of crystal violet dye. The maximum dye removal efficiency (96.1%) obtained at pH 5.5 and at 70°C with 1.13g of adsorbent dosage using 40 ppm dye solution concentration in 10 days of contact time.
- An activated carbon prepared from *Sargassum wightii* seaweeds using HCl (0.1N) and NaOH used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (98.3%) obtained at pH 7 and at 30°C in 60 minutes of contact time with 0.2g of adsorbent dosage using 80 ppm dye solution concentration. The adsorption process followed pseudo second order kinetic equation. Thermodynamic study revealed that adsorption process was spontaneous, feasible and endothermic in nature. [Jayganesh *et al.* (2017)].

- **Santhi *et.al* (2011)** prepared activated carbon from cucumis sativa fruit using NaOH (0.1M) and used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (92.15%) obtained at pH 7 and at 27°C in 90 minutes of contact time with 0.2g of adsorbent dosage using 25 ppm dye solution concentration. The maximum adsorption capacity obtained from Langmuir adsorption isotherm equation was found to be 34.24 mg g<sup>-1</sup>. The adsorption of crystal violet dye followed pseudo second order rate equation and fitted well with both Langmuir and Freundlich adsorption isotherms.
- An activated carbon prepared from Syzygium cumini seed used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (99%) obtained at pH 11 and at 30°C in 60 minutes of contact time with 50mg of adsorbent dosage using 10 ppm dye solution concentration. The adsorption data fitted with both Langmuir and Freundlich isotherms models and followed pseudo first order kinetic equations. [**Meenakshi sundaram *et.al* (2017)**].
- **Chekwube *et.al* (2017)** prepared activated carbon from kolanut pod husk using H<sub>2</sub>SO<sub>4</sub> and used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (96.5%) was achieved at pH 8 and at 30°C in 60 minutes of contact time with 1.0g of adsorbent dosage using 100 ppm dye solution concentration. The adsorption data well fitted to pseudo second order kinetic model. The thermodynamic study revealed that adsorption is spontaneous, feasible and exothermic in nature.
- **Khanam *et.al* (2017)** investigated the adsorption of crystal violet dye for the adsorbent Banyan leaf powder (BLP) from aqueous solution. The maximum dye removal efficiency (95%) was achieved at pH 8 and at 25°C in 120 minutes of contact time with 0.25g of adsorbent dosage using 200 ppm dye solution concentration. The adsorption kinetics followed pseudo second order kinetic model. The equilibrium adsorption described well by Langmuir adsorption isotherm and the maximum adsorption capacity obtained for the adsorption of crystal violet dye onto BLP was found to be 81 mg/g.

- **Aljeboree *et.al* (2016)** used fugas sawdust as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (98%) was achieved at pH 10 and at 25°C in 1 hour of contact time with 0.5g of adsorbent dosage using 10 ppm dye solution concentration. The thermodynamic study revealed that adsorption process was spontaneous, feasible and endothermic in nature.
  
- **Ghadah Alsenani *et.al* (2021)** used calligonum comosum leaf powder (CCLP) as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (98.96%) obtained at pH 7 and at 25°C in 4 hours of contact time using 100 ppm dye solution concentration with 0.5g of adsorbent dosage. The adsorption data followed both Langmuir and Freundlich adsorption isotherms and the thermodynamic studies indicated the adsorption is exothermic in nature.
  
- An activated carbon prepared from cassia fistula fruit shell treated with sulphuric acid used for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (85%) was achieved at pH 8 and at 30°C in 80 minutes of contact time with 60mg of adsorbent dosage using 35 ppm dye solution concentration. The thermodynamic study indicates the adsorption process is endothermic in nature. [**Savithril *et.al* (2018)**].
  
- **Shamik Chowdhury *et.al* (2012)** used ananas comosus (pineapple) leaf powder (PLP) as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (96%) obtained at pH 8 and at 40°C in 3 hours of contact time with 2g of adsorbent dosage using 50 ppm dye solution concentration. Thermodynamic study revealed that adsorption process was spontaneous and endothermic in nature. The adsorption followed pseudo second order kinetic model.
  
- **Mahdavinia *et.al* (2013)** used kappa carrageenan beads as an adsorbent for the removal of crystal violet dye from water. The maximum dye removal efficiency (91%) obtained at pH 10 and at 60°C in ≈110 minutes of contact time with 0.1g of adsorbent dosage using 20 ppm dye solution concentration. The adsorption process of crystal violet dye followed pseudo second order kinetics and Freundlich adsorption isotherm model found to be the best

adsorption isotherm model for the adsorption of crystal violet dye onto adsorbent used in this study.

- An activated carbon prepared from corn cobs and corn roots using  $H_3PO_4$  (80%) used as an adsorbents for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (88%) for the corn cobs adsorbent (PAC-CC) was achieved at pH 10 and at 25°C in 30 minutes of contact time with 3.5g of adsorbent dosage using 20 ppm dye solution concentration. The maximum dye removal efficiency (87%) for the corn roots adsorbent (PAC-CR) was achieved at pH 10 and at 25°C in 30 minutes of contact time with 3.5g of adsorbent dosage using 20 ppm dye solution concentration. The maximum adsorption capacities were 41.80 mg/g (PAC-CR). The experimental data revealed that crystal violet adsorption process followed pseudo second order kinetic model and Langmuir adsorption isotherm. [Tucheka *et.al*(2021)].
  
- **Enenebeaku *et.al* (2016)** used picrilima nitida stem bark powder (PNSB) as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (70%) obtained at pH 10 and at 70°C in 120 minutes of contact time with 4g of adsorbent dosage using 125 ppm dye solution concentration. The adsorption of crystal violet onto PNSB followed Freundlich adsorption isotherm and second order kinetic rate equation.
  
- **Hazrat Ali *et.al* (2008)** used calotropis procera leaf biomass as an adsorbent for the removal of crystal violet dye from water. The maximum dye removal efficiency (91.56%) was achieved at pH 7.2 and at 30°C in 60 minutes of contact time with 1g of adsorbent dosage using 60 ppm concentration of dye solution.
  
- **Chieng *et.al* (2021)** used sauropus androgynus treated with NaOH (0.1M) as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (50%) obtained at pH 12 and at 60°C in 120 minutes of contact time with 0.05g of adsorbent dosage using 25 ppm dye solution concentration. The adsorption process is exothermic in nature as revealed by the thermodynamic study.

- **Abbas *et.al* (2021)** prepared a low cost adsorbent from peanut husk using KOH (0.1M) and used for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (90%) obtained at pH 8 and at 60°C in 120 minutes of contact time with 1.0g of adsorbent dosage using 100 ppm dye solution concentration. The experimental data well fitted with both Langmuir and Freundlich adsorption isotherm models.
- **Dahri *et.al* (2017)** used *Artocarpus odoratissimus (Tarap)* core as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (90%) obtained at pH 10 and at 65°C in 2 hours of contact time with 0.06g of adsorbent dosage using 500ppm dye solution concentration. The thermodynamic study revealed that adsorption of crystal violet was feasible and endothermic in nature.
- **Abdul Karim *et.al* (2015)** converted sugarcane fiber into a low cost activated adsorbent using HNO<sub>3</sub> (0.1M) and used for the removal of crystal violet dye from water. The maximum dye removal efficiency (95%) obtained at pH 11 and at 25°C in 24 hours of contact time with 50 mg of adsorbent dosage using 200 ppm concentration of dye solution.
- An activated carbon prepared from cowpea (*vigno unguiculate*) husks, by treating with 10% H<sub>3</sub>PO<sub>4</sub> used for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (99.8%) obtained at pH 7 and at 60°C in 60 minutes of contact time with 0.1g of adsorbent dosage using 1000 ppm concentration of dye solution. The adsorption data fitted well with Freundlich adsorption isotherm. Adsorption process followed pseudo second order kinetic model. Thermodynamic of adsorption process indicates that the adsorption process was found to be spontaneous and feasible in nature. [**Ayuba *et.al* (2020)**].
- **Bakhtyar *et.al* (2015)** investigated the adsorption of crystal violet dye from aqueous solution using walnut shell powder as a low cost solid adsorbent. The maximum dye removal efficiency (50%) was achieved at pH 7.5 and at 30°C in 400 minutes of contact time with 0.5g of adsorbent dosage using 300 ppm dye solution concentration. The adsorption

followed pseudo second order kinetic model and the adsorption data well fitted to Freundlich adsorption isotherm model.

- An activated carbon prepared from *Gracilaria corticata* seaweeds used as a low cost , ecofriendly adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (95%) was achieved at pH 10 and at 30°C in 90 minutes of contact time with 0.5g of adsorbent dosage using 100 ppm concentration of dye solution. The kinetics of adsorption followed pseudo second order rate equation. The adsorption data described well by both Freundlich and Langmuir adsorption isotherms. [**Chiang Mai *et.al* (2018)**].
- An activated carbon prepared from Golbasi lignite using  $ZnCl_2$  used as an adsorbent for the removal of crystal violet dye. The maximum dye removal efficiency (93%) obtained at pH 5.8 and at 20°C in 60 minutes of contact time with 0.1g of adsorbent dosage using 50 ppm dye solution concentration. The adsorption process is well described by pseudo second order kinetic equation. According to thermodynamic study adsorption is endothermic in nature. [**Depci *et.al* (2012)**].
- **Hussein *et.al* (2019)** used fennel seeds as a low cost adsorbent for the removal of crystal violet dye. The maximum dye removal efficiency (86%) obtained at pH 4 and at 80°C in 60 minutes of contact time with 5g of adsorbent dosage using 20 ppm concentration of dye solution. The adsorption of crystal violet dye followed Freundlich adsorption isotherm.
- **Buhani *et.al* (2021)** prepared activated carbon from palm oil shells coated by  $Fe_3O_4$  and used for the removal of crystal violet dye from water. The maximum dye removal efficiency (99.15%) was achieved at pH 10 and at 27°C in 90 minutes of contact time with 2.5g of adsorbent dosage using 10 ppm dye solution concentration. The crystal violet dye adsorption followed pseudo second order kinetic model.

- **Ali Haki *et.al* (2021)** prepared modified avocado shells using NaOH-AS and used as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (96.9%) was achieved at pH 8 and at 25°C in 150 minutes of contact time with 2.5g of adsorbent dosage using 300 ppm concentration of dye solution. The thermodynamic study showed that crystal violet dye adsorption onto NaOH-AS was spontaneous, feasible and exothermic in nature. The crystal violet dye adsorption followed pseudo second order kinetic model.
- **Mosoarca *et.al* (2021)** used lilac tree leaf powder as a natural adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (85%) obtained at pH 10 and at 35°C in 30 minutes of contact time with 2.5g of adsorbent dosage using 50 ppm dye solution concentration. The thermodynamic study revealed that adsorption process was spontaneous and endothermic in nature. Adsorption followed pseudo second order kinetic model and Langmuir adsorption isotherm.
- An activated carbon prepared from cocoa (*theobroma*) shell using H<sub>2</sub>SO<sub>4</sub> (50%) used as an adsorbent for the removal of crystal violet dye from waste water. The maximum dye removal efficiency (81%) obtained at pH 8 and at 35°C in 90 minutes of contact time with 50 mg of adsorbent dosage using 100 ppm dye solution concentration. The adsorption data fitted well with pseudo second order kinetic model, and followed intra particle diffusion. [Mylsamy shankar *et.al* (2016)].
- **Messaoudi *et.al* (2016)** used date stones as an adsorbent for the removal of crystal violet dye from aqueous medium. The maximum dye removal efficiency (96.36%) was achieved at pH 10 and at 50°C in 180 minutes of contact time with 8g of adsorbent dosage using 800 ppm dye solution concentration. Thermodynamic study shows that the adsorption was feasible, spontaneous and endothermic in nature. Equilibrium data were fitted to Langmuir adsorption isotherm model. Pseudo second order kinetic equation well described the adsorption process.

- **Arti Jain *et.al* (2012)** used spent tea leaves (STL) as an adsorbent for the removal of crystal violet dye from water. The maximum dye removal efficiency (37%) obtained at pH 8 and at 50°C in 1 hour of contact time with 0.01g of adsorbent dosage using 50 ppm dye solution concentration. The adsorption process was spontaneous and endothermic in nature. The adsorption data well fitted with both Langmuir and Freundlich adsorption isotherm model.
- **Syed Noeman *et.al* ( 2021)** used Nutraceutical industrial fenugreek seed spent as a low cost adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (95%) obtained at pH 7 and at 50°C in 165 minutes of contact time with 0.3g of adsorbent dosage using 300 ppm dye solution concentration. The kinetic study confirm the pseudo second order model. The thermodynamic study indicated that adsorption process was spontaneous, feasible and endothermic, physical in nature.

#### **NANO ADSORBENTS**

- **Hamidzadeh *et.al* (2015)** prepared magnetically modified activated carbon and used for the removal of crystal violet dye from water. The maximum dye removal efficiency of the adsorbent used in this study was found to be (90%) under the following experimental conditions : adsorbent dosage 1g ,crystal violet dye solution concentration : 100 ppm,contact time : 10 minutes, pH 9,temperature 70°C. The adsorption process followed pseudo second order kinetic equation.
- **Sandeep kumar *et.al* ( 2014)** investigated the adsorption of crystal violet dye on to multi walled carbon nano tubes. The maximum dye removal efficiency (90%) was achieved at pH 7 and at 75°C in 30 minutes of contact time with 0.01 mg of adsorbent dosage using 10ppm dye solution concentration. The adsorption of crystal violet dye followed pseudo second order kinetic model. The adsorption data fitted well with Langmuir adsorption isotherm.
- **Dehghan Abkenar *et.al* (2016)** prepared magnetic modified Fe<sub>3</sub>O<sub>4</sub> and used as an adsorbent for the removal of crystal violet dye from water. The maximum dye removal efficiency (98%) obtained at pH 11 and at 65°C in 15 minutes of contact time with 0.015g of adsorbent

dosage using 20 ppm dye solution concentration. The experimental data well fitted with Langmuir adsorption isotherm model.

- Adsorption of crystal violet dye onto nano ferrite modified with surfactant sodium dodecyl sulphate (SDS) was investigated. The maximum dye removal efficiency (85%) obtained at pH 10 and at 40°C in 3 hours of contact time with 0.5g of adsorbent dosage using 50 ppm dye solution concentration. The adsorption kinetics followed pseudo second order kinetic model. The adsorption process was spontaneous in nature revealed the thermodynamic study.[**Kumar *et.al* (2017)**].
- **Sagnik Chakraborty *et.al* (2021)** prepared natural fly ash modified with calcium oxide adsorbent and used for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (97.86%) obtained at pH 8 and at 80°C in 3 hours of contact time with 2g of adsorbent dosage using 50 ppm dye solution concentration. The adsorption of crystal violet dye was spontaneous and exothermic in nature. The adsorption experimental data obeyed Langmuir adsorption isotherm.

#### **BIO-WASTE ADSORBENTS**

- **Meriem Zamouche *et.al* (2020)** used cedar cone forest waste as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (99.62%) was achieved at pH 7 and at 45°C in 5 days of contact time with 2.5g of adsorbent dosage using 50 ppm dye solution concentration. The adsorption data well fitted with both Langmuir and Freundlich adsorption isotherm models.

#### **NOVEL ADSORBENTS:**

- **Augusto Cezar *et.al* (2017)** used *Eragrostis plana* nees (EPN) as an ecofriendly adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (93%) obtained at pH 8 and at 20°C in 180 minutes of contact time with 0.59g of adsorbent dosage using 50 ppm dye solution concentration. The thermodynamic data indicated that the adsorption was spontaneous, endothermic and physical process. The

adsorption kinetics of crystal violet onto EPN well described by pseudo second order kinetic model.

- **Rajurkar *et.al* (2015)** used chitosan leaves and saraca indica leaves as adsorbents for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (98.29%) for the chitosan leaves adsorbent was achieved at pH 3 and at 50°C in 40 minutes of contact time with 0.6g of adsorbent dosage using 10 ppm dye solution concentration. The maximum dye removal efficiency (97.61%) for saraca indica leaves adsorbent achieved at pH 3 and at 50°C in 30 minutes of contact time with 0.2g of adsorbent dosage using 10ppm dye solution concentration. Adsorption kinetics followed pseudo second order kinetics with both the adsorbents used in this study. The adsorption of crystal violet dye followed Freundlich adsorption isotherm, with the adsorbent chitosan leaves and Langmuir adsorption isotherm with the adsorbent saraca indica leaves.
  
- **Song *et.al* (2019)** used epichlorohydrin modified corncob treated with NaOH as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (65%) was achieved at pH 12 and at 60°C in 24 hours of contact time with 0.1g of adsorbent dosage using 50 ppm dye solution concentration. The adsorption kinetics well described by pseudo second order model.
  
- Actinidia deliciosa peels powder (*polyacryl amide grafted*) activated using HCl and NaOH (0.5M) and used an eco friendly, low cost adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (89%) was achieved at pH 7.3 and at 80°C in 180 minutes of contact time with 0.025g of adsorbent dosage using 20 ppm dye solution concentration. The experimental data were best fitted to Langmuir adsorption isotherm and obeyed pseudo second order kinetics model.[**Rais Ahmad *et.al* (2020)**].

## POLYMER ADSORBENTS

- **Feza Geyikci *et.al*(2012)** used HNO<sub>3</sub> treated montmorillonite as an adsorbent for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency(99.94%) was achieved at pH 8 and at 80°C in 60 minutes of contact time with 0.5g of adsorbent dosage using 50 ppm dye solution concentration. The adsorption data fitted well with both Langmuir and Temkin adsorption isotherms. The adsorption followed pseudo second order kinetic model.
  
- **Miyah *et.al* (2017)** prepared an activated carbon from Moroccan pyrophyllite using HCl and NaOH and used for the removal of crystal violet dye from aqueous solution. The maximum dye removal efficiency (83%) obtained at pH 6.8 with 10mg of adsorbent dosage in 120 minutes of contact time, when the initial concentration of dye solution used is 150 ppm at 20°C. Thermodynamic studies indicated that dye adsorption process was spontaneous, physisorption and endothermic in nature.



## ECO FRIENDLY LOW COST ADSORBENTS USED FOR THE REMOVAL OF THE DYE CRYSTAL VIOLET

In the present study, a review on eco friendly, low cost adsorbents used for the removal of crystal violet dye from aqueous solution and waste water carried out. About 150 research papers with low cost and eco friendly adsorbents used for the removal of crystal violet dye from aqueous solution were collected and reviewed. The experimental conditions at which the maximum removal of crystal violet dye obtained using these low cost adsorbents are discussed in the following table.

S. No	Adsorbent source	Adsorbent dose	Initial Concentration of crystal violet dye	Contact Time	pH	Temperature	Crystal violet dye removal efficiency of the adsorbent
1.	Granular red mud maize straw adsorbent	2g	600ppm	24 hours	11	65°c	≈100%
2.	<i>Rricinus communis pericarp</i> activated carbon adsorbent (activated using 50% sulphuric acid)	25mg	50ppm	12 hours	7	45°c	≈100%
3.	Mchounche clay (MC) dry powder adsorbent	32.8mg	20ppm	240 minutes	7	60°c	≈100%
4.	Black turmeric Rhizomes ash adsorbent	30mg	10ppm	24 hours	9	45°c	99.95%
5.	Montmorillonite clay adsorbent	0.5g	50ppm	60 minutes	8	80°c	99.94%
6.	Mango leaves biochar (MLBC) powder adsorbent	0.5g	10ppm	60 minutes	8	47°c	99.85%
7.	Cedar cone forest waste adsorbent	2.5g	50ppm	5 days	7	45°c	99.62%

8.	Bamboo based lignin (LBM) bamboo fabrics adsorbent	5g	150ppm	30 minutes	8	70°C	99.32%
9.	Palm oil shells activated carbon coated with Fe <sub>3</sub> O <sub>4</sub> adsorbent (activated using 10% phosphoric acid)	2.5g	10ppm	90 minutes	10	27°C	99.15%
10.	<i>Rhizophora mucronate</i> activated carbon adsorbent (activated using sodium chloride)	0.5g	250ppm	60 minutes	7	25°C	99.8%
11.	Cowpea ( <i>vigna unguiculata</i> ) husk activated carbon adsorbent (activated using 10% phosphoric acid)	0.1g	1000ppm	60 minutes	7	60°C	99.8%
12.	Crossed linked grafted xanthan gum copolymer	40mg	500ppm	7 hours	7	30°C	99.7%
13.	<i>Tectona grandis</i> sawdust (TGSD) powder adsorbent	2g	50ppm	180 minutes	7	25°C	99.6%
14.	<i>Artocarpus heterophyllus</i> (jackfruit) leaf powder (JLP) adsorbent	1g	50ppm	120 minutes	7	20°C	99.5%
15.	Coniferous pinus bark powder (CPBP) adsorbent	1g	20ppm	120 minutes	8	65°C	99.5%
16.	Ground rice straw activated using citric acid used as an adsorbent	0.5g	100ppm	24 hours	7	30°C	99.5%
17.	Sodium dodecyl sulfate (SDS) an (anionic surfactant) surface modified neutral alumina used as an adsorbent	6g	200ppm	60 minutes	6.7	25°C	99%

18.	<i>Syzygium cumini</i> seed acid activated carbon adsorbent	50mg	10ppm	60 minutes	11	30°c	99%
19.	A compound composed of multi walled carbon nano tubes with chitosan used as an adsorbent	0.0035g	100ppm	90 minutes	7	20°c	99%
20.	<i>Calligonum comosum</i> leaf powder (CCLP) adsorbent	0.5g	100ppm	4 hours	7	25°c	98.96%
21.	<i>Murraya koenjii</i> stem biochar adsorbent	100mg	10ppm	60 minutes	6	35°c	98.33%
22.	Chitosan leaves powder adsorbent (dried leaves powder)	0.6g	10ppm	40 minutes	3	50°c	98.29%
23.	Grape fruit peel (GFP) powder adsorbent	1g	25ppm	30 minutes	6	30°c	98.25%
24.	Amino silica adsorbent	0.35g	200ppm	64 minutes	10	33°c	98.9%
25.	<i>Sargassm wightii</i> seaweeds activated carbon adsorbent (activated using hydrochloric acid and sodium hydroxide)	0.2g	80ppm	60 minutes	7	30°c	98.3%
26.	<i>Eichhornia crassipes</i> modified with sodium dodecyl sulfatate (SDS used as an adsorbent)	1g	20ppm	100 minutes	8	50°c	98.3%
27.	Agrowaste (Groundnut shell and orange peel) activated carbon adsorbent	5g	10ppm	45 minutes	8	80°c	98.3%
28.	Waste Coffee husk dry powder adsorbent	1.5g	50ppm	10 minutes	3	60°c	98%

29.	Leucaena leucocephala ( <i>subabul</i> ) seed pods activated carbon adsorbent (activated using sodium hydroxide)	2g	10ppm	30 minutes	11	50°c	98%
30.	Fugas sawdust carton(FSC) adsorbent	0.5g	10ppm	1 hour	10	25°c	98%
31.	Magnitide nano particles (Fe <sub>3</sub> O <sub>4</sub> ) coated with tannic acid used as an adsorbent	0.015g	20ppm	15 minutes	11	65°c	98%
32.	Ananas comosus (pineapple) leaf powder adsorbent	0.2g	50ppm	40 minutes	8	50°c	98%
33.	<i>Holarrhena antidysenterica</i> activated using 10% tartaric acid used as an adsorbent	0.8g	150ppm	35 minutes	5	40°c	98%
34.	Natural fly ash combined with calcium oxide used as an adsorbent	2g	50ppm	3 hours	8	80°c	97.86%
35.	Saraca indica leaves powder adsorbent (dried leaves powder)	0.2g	10ppm	30 minutes	3	50°c	97.61%
36.	Corn starch nano particle citrate based adsorbent	50 mg	500ppm	240 minutes	8.5	55°c	97.7%
37.	Rice bran waste modified with chlorosulfonic acid is used as an adsorbent	2g	100ppm	60 minutes	7	25°c	97.4%
38.	Polyaniline/ <i>Tectona Grandis</i> sawdust composite used as an adsorbent	0.8g	50ppm	120 minutes	7	30°c	97.3%

39.	Papaya seed powder adsorbent	12g	40ppm	12 hours	8	25°c	97.3%
40.	Sulphuric acid treated sawdust ( <i>Parkia biglobosa</i> ) adsorbent	68.39mg	1000ppm	275 minutes	10	60°c	97.2%
41.	Ecuadorian black ( <i>Quilotoa</i> ) sand used photocatalytic adsorbent	9g	40ppm	2 hours	8	30°c	97.1%
42.	Ecuadorian black ( <i>Mompiche</i> ) sand used as photocatalytic adsorbent	9g	40ppm	2 hours	8	25°c	97%
43.	Anatolian black pine ( <i>Pinus nigra</i> Arnold) adsorbent	15g	200ppm	240 minutes	10	45°c	96.60%
44.	Arginine - doped heliotrope leaves adsorbent	0.75g	20ppm	90 minutes	6	25°c	96.54%
45.	Date stones powder adsorbent	8g	800ppm	180 minutes	10	50°c	96.36%
46.	<i>Green peas shell powder</i> activated carbon adsorbent (activated using Conc.Sulphuric acid)	1g	100ppm	60 minutes	7	60°c	96.25%
47.	Avocado shells powder (ASP) activated carbon adsorbent (activated using sodium hydroxide)	2.5g	300ppm	150 minutes	8	25°c	96.9%
48.	Kolanut pod husk activated carbon adsorbent (KPAC) (activated using sulphuric acid)	1g	100ppm	60 minutes	8	30°c	96.5%
49.	Active sludge adsorbent (activated using KOH (1:1))	6g	100ppm	150 minutes	9	55°c	96.2%

50.	Poly(acrylamide)-kaolin(PAAM-K) nanocomposite hydrogel adsorbent	2g	30ppm	5 hours	10	35°c	96%
51.	<i>Aspergillus niger</i> mycelia fungus adsorbent	1.13g	40ppm	10 days	5.5	70°c	96%
52.	Pectin based graft Copolymer - ZnO hybrid nano composite used as an adsorbent	0.5g	400ppm	15 minutes	13	50°c	96%
53.	Ananas comosus ( <i>pineapple</i> ) leaf powder adsorbent	2g	50ppm	3 hours	8	40°c	96%
54.	Pecan pericarp ( <i>Carya illinoensis</i> ) powder adsorbent activated using hydrochloric acid	5g	600ppm	60 minutes	7	50°c	96%
55.	Eucalyptus wood Carbonized (EWC) char adsorbent	1g	10ppm	15 minutes	9	40°c	95.80%
56.	Rice husk activated using succinic acid used as an adsorbent	0.25g	50ppm	240 minutes	8	50°c	95.65%
57.	<i>Terminalia arjuna</i> sawdust powder (TASD) adsorbent	6g	50ppm	120 minutes	7	25°c	95.58%
58.	Gracilaria corticata seaweeds activated carbon adsorbent (activated using 1:1 sulphuric acid)	0.5g	100ppm	90 minutes	10	30°c	95%
59.	Sugarcane fiber activated carbon adsorbent (activated using nitric acid and sodium hydroxide)	50mg	200ppm	24 hours	11	25°c	95%

60.	<i>Mango kernel</i> activated carbon adsorbent (activated using hydrochloric acid)	0.075g	100ppm	2 hours	9	35°c	95%
61.	Tamarind seed powder activated carbon adsorbent (activated using hydrochloric acid)	5g	500ppm	4 hours	11	60°c	95%
62.	<i>Banyan leaf</i> powder (BLP) adsorbent	0.25g	200ppm	120 minutes	8	25°c	95%
63.	Nutraceutical industrial fenugreek seed spent (NIFGS) adsorbent	0,3g	300ppm	165 miutes	7	50°c	95%
64.	Bactericidal filter containing biodegradable polymers used as an adsorbent	40mg	50ppm	6 hours	7	30°c	94.4%
65.	<i>Citrullus colocynthis</i> activated using 10%tartaric acid used as an adsorbent	0.6g	125ppm	30 minutes	4	40°c	94%
66.	White Rot Fungus ( <i>Phanerochaete chrysosporium</i> ) adsorbent	0.8g	25ppm	40 minutes	6	50°c	94%
67	Potato peel ( <i>solanum tuberosum</i> ) activated carbon adsorbent (activated using hydrochloric acid and sodium hydroxide)	1.5g	200ppm	20 minutes	6	30°c	93.45%
68	Acrylic-lignosulfonate resin (ALR) powder adsorbent	50mg	200ppm	24 hours	12	25°c	93.6%
69	<i>Ocotea puberula</i> bark powder (OPBP) adsorbent	0.75g	50ppm	90 minutes	9	55°c	93.3%

70	Golbasi lignite activated carbon adsorbent (activated carbon prepared by mixing zinc chloride and lignite in 1:1 ratio)	0.1g	50ppm	60 minutes	5.8	20°c	93%
71	Eragrostis plana nees (EPN) powder adsorbent	0.59mg	50ppm	180 minutes	8	20°c	93%
72	Waste Crab Shells activated carbon adsorbent (activated using hydrochloric acid and sodium hydroxide)	0.68g	75ppm	30 minutes	12	20°c	93%
73	Tropical wild fern ( <i>Diplazium esculentum</i> ) activated carbon adsorbent (activated using sodium hydroxide)	500mg	250ppm	180 minutes	8	70°c	92.47%
74	<i>Cucumis sativa</i> fruit peel powder (CCS) adsorbent	0.2g	25ppm	90 minutes	7	27°c	92.15%
75	Rubber seed shell (RSS) powder activated carbon adsorbent (activated using ammonium chloride)	5g	10ppm	75 minutes	10	30°c	92.08%
76	Mycelial biomass of <i>Ceriporia lacerate</i> (CLB) powder adsorbent	20g	100ppm	24 hours	6	28°c	92%
77	Calotropis procera leaves powder biomass adsorbent	1g	6ppm	60 minutes	7.2	30°c	91.56%
78	<i>Cheatophora elegans</i> alga powder adsorbent	100mg	40ppm	4 hours	5.6	22°c	91%
79	Eichhornia plant carbon adsorbent	1g	20ppm	150 minutes	8	40°c	91%

80	Kappa carrageenan beads used as adsorbent	0.1g	20ppm	≈110 minutes	10	60°c	91%
81	Punica granatum Shell (PGS) powder carbon adsorbent	0.6g	25ppm	2 hours	5	25°c	90.5%
82	Activated carbon derived from male flowers of coconut tree (activated using phosphoric acid and sulphuric acid mixture)	25 mg	40ppm	180 minutes	6	28°c	90%
83	Platanus orientalis ( <i>chinar tree</i> ) dried leaf powder adsorbent	2.5g	20ppm	40 minutes	6.52	60°c	90%
84	Multi walled carbon nano tube adsorbent	0.01mg	10ppm	30 minutes	7	75°c	90%
85	<i>Mentha piperita</i> activated carbon adsorbent (activated using hydrochloric acid and sulphuric acid mixture)	1g	100ppm	75 minutes	7	80°c	90%
86	Tarap fruits core powder adsorbent	0.06g	500ppm	2 hours	10	65°c	90%
87	Raw bamboo chips (RBC) adsorbent	10g	50ppm	60 minutes	7	45°c	90%
88	Vitreous tuff mineral powder (collected from santiago de Cuba) adsorbent	500mg	25ppm	3 hours	5	30°c	90%
89	Sodium carbonate treated bamboo chips (NCBC)	10g	100ppm	60 minutes	7	25°c	90%
90	Peanut husk adsorbent	1g	100ppm	120 minutes	8	60°c	90%
91	Iron oxide nano magnet loaded with commercial activated carbon used as an adsorbent	1g	100ppm	10 minutes	9	70°c	90%

92	<i>Nostoc linckia</i> activated carbon adsorbent (activated using sodium hydroxide)	9g	200ppm	24 hours	9	80°c	90%
93.	<i>Sargassum swartzii</i> seaweeds activated carbon (SWAC) adsorbent (activate using sulphuric acid)	200mg	100ppm	120 minutes	8	60°c	90%
94	Chenopodium album	6mg	10ppm	24 hours	7	25°c	89.5%
95	Pistachio shell powder (PSP) adsorbent	4g	10ppm	360 minutes	6	22°c	89.5%
96	Actinida delicious peel powder (polyacryl amide grafted) activated carbon adsorbent (activated using hydrochloric acid and sodium hydroxide)	0.025g	20ppm	180 minutes	7.3	80°c	89%
97	Date palm fiber activated carbon adsorbent (activated using sodium hydroxide)	0.25g	25ppm	150 minutes	7	55°c	89%
98	Water hyacinth plant root (dried root powder) adsorbent	1g	500ppm	120 minutes	7.8	27°c	88.89%
99	Kokum ( <i>Garcinia Indica</i> ) leaf powder activated adsorbent (activated using 20% formaldehyde and dilute sulphuric acid)	1g	50ppm	90 minutes	6	60°c	88.13%
100	Corn cobs activated carbon adsorbent (activated using phosphoric acid)	3.5g	20ppm	30 minutes	10	25°c	88%

101	Bathurst Burr ( <i>Xanthium spinosum</i> ) powder adsorbent	2g	100ppm	30 minutes	7	21°C	87.15%
102	Oak leaves activated carbon adsorbent (activated using phosphoric acid (1:1))	30mg	100ppm	20 minutes	7	100°C	87.8%
103	Olive leaves powder (OLP) activated carbon adsorbent (activated using Sodium hydroxide and hydrochloric acid)	0.1g	50ppm	24 hours	7.5	60°C	87.6%
104	Carbon dioxide plasma treated polyvinylidene fluoride (PVDF) electrospun membrane used as an adsorbent	0.06g	10ppm	25 minutes	7	29°C	87.6%
105	Diaporthe schini inactive fungus biomass adsorbent	4g	300ppm	24 hours	7.5	25°C	87%
106	Corn roots activated carbon adsorbent (activated using phosphoric acid)	3.5g	20ppm	30 minutes	10	25°C	87%
107	Black Gram Seed Husk (BGSH) powder adsorbent	0.5mg	50ppm	35 minutes	8	53°C	86.43%
108	Laterite Soil modified using sodium dodecyl sulphate (SDS) used as an adsorbent	5mg	250ppm	60 minutes	6	25°C	86.5%
109	Palm Kernel Shell derived Biochar (BC-PKS) adsorbent	0.5g	400ppm	24 hours	6	25°C	86.4%
110	Fennel seeds powder adsorbent	5g	20ppm	60 minutes	4	80°C	86%
111	Chitin psyllium - aerogel adsorbent	2.5g	1000ppm	2 hours	8	25°C	86%

112	Lignin rich isolate (extracted from elephant grass and stalk) adsorbent	2g	50ppm	30 minutes	7	30°c	85.64%
113	<i>Balanites aegyptiaca</i> seed shell activated carbon adsorbent (activated using sodium hydroxide)	1.0g	50ppm	90 minutes	8	30°c	85.29%
114	Cassia fistula fruit shell activated carbon adsorbent (activated using sulphuric acid)	60mg	35ppm	80 minutes	8	30°c	85%
115	Nano zinc ferrite modified with sodium dodecyl sulphate (SDS)used as an adsorbent	0.5g	50ppm	3 hours	10	40°c	85%
116	Lilac tree leaf powder adsorbent	2.5g	50ppm	30 minutes	10	35°c	85%
117	Fiber felt thermal activated carbon adsorbent	200mg	40ppm	60 minutes	10	27°c	85%
118	<i>Pomegranate peel</i> activated carbon adsorbent (activated using phosphoric acid)	0.1g	100ppm	60 minutes	11	26°c	85%
119	Macro-fungal ( <i>Agaricus bisporus</i> ) adsorbent	0.5g	100ppm	210 minutes	4.6	25°c	84.9%
120	Moroccan pyrophyllite activated carbon adsorbent (activated using hydrochloric acid and sodium hydroxide)	10mg	150ppm	120 minutes	6.8	20°c	83%
121	Corn stalk activated carbon adsorbent (activated by heating in an oven at 80°c for 12hours)	0.3g	50ppm	120 minutes	8	80°c	82%

122	Tea dust (TD) activated carbon adsorbent (activated using hydrochloric acid)	0.2g	200ppm	90 minutes	7.5	40°c	82%
123	Cocoa (theobroma) shell activated carbon (CSAS) adsorbent (activated using 50% sulphuric acid)	40mg	100ppm	90 minutes	8	35°c	81%
124	<i>Powdered grape seeds</i> (PGS) activated carbon adsorbent (activated using nitric acid and sodium hydroxide)	2g	500ppm	90 minutes	6.8	25°c	80%
125	<i>Nocardia coralline</i> microorganism adsorbent	0.05mg	50ppm	90 minutes	7	25°c	80%
126	<i>Artocarpus altilis</i> ( <i>breadfruit</i> ) skin used as an adsorbent	0.05g	10ppm	30 minutes	4.7	25°c	80%
127	Wollastonite adsorbent	1g	50ppm	120 minutes	7.5	30°c	79.82%
128	Synthesised Chitin nano whiskers (ChNW) (from shrimp shell) used as an adsorbent	2g	250ppm	2 hours	6	80°c	79.13%
129	Almond shell powder adsorbent	0.4g	10ppm	180 minutes	7	20°c	79%
130	<i>Pseudomonas putida</i> (biological strain) adsorbent	5.22g	60ppm	12 hours	7.5	37°c	78.5%
131	Gum arabic- <i>cl</i> -poly (acrylamide) nanohydrogel adsorbent	0.2g	100ppm	90 minutes	9	35°c	76%
132	<i>Paddle cactus</i> biomass ( <i>Tacinga palmadora</i> ) powder adsorbent	0.5g	100ppm	60 minutes	10	25°c	75%

133	Elodea Canadensis, a fresh water submerged macrophyte species used as an adsorbent	4g	30ppm	9 days	7	40°C	72%
134	Raw tunisian Smectite Clay (RSC) adsorbent	0.3g	100ppm	60 minutes	11	25°C	71.9%
135	<i>Sida Rhombifolia</i> (SRAC) charcoal adsorbent (activated using conc. sulphuric acid)	0.050g	50ppm	50 minutes	7	25°C	70.21%
136	Picrilima nitida stem bark powder (PNSB)	4g	125ppm	120 minutes	10	70°C	70%
137	Khulays Natural Bentonite adsorbent	0.125g	300ppm	40 minutes	7	25°C	69%
138	<i>African star apple</i> (ASA) whole seed powder activated Carbon adsorbent (activated using phosphoric acid)	1g	50ppm	2 hours	7	30°C	65%
139	Corn cob modified with epichlorohydrin (EMC) activated carbon adsorbent (activated using sodium hydroxide)	0.1g	50ppm	24 hours	12	60°C	65%
140	Zeolite A (synthesized from Coal fly ash) adsorbent	1g	20ppm	60 minutes	6	30°C	62.8%
141	<i>Groundnut shell</i> activated carbon adsorbent (activated using hydrochloric acid)	0.1g	100ppm	30 minutes	10	85°C	62%
142	Magnetic Fe <sub>3</sub> O <sub>4</sub> @SiO <sub>2</sub> starch-graft-poly acrylic acid (SPAA) nanocomposite hydrogel adsorbent	25mg	50ppm	24 hours	7	25°C	60%

143	Bitter apple peel derived photoactive carbon dots used as an adsorbent	10mg	20ppm	90 minutes	7	100°c	60%
144.	Egyptian Doum Fruit powder adsorbent	30mg	20ppm	60 minutes	7	25°c	58%
145.	Activated bentonite adsorbent (activated using conc.sulphuric acid)	0.05g	300ppm	90 minutes	7	30°c	50%
146	<i>Parkia speciosa seed</i> (Petai) pod activated carbon adsorbent (activated using hydrochloric acid and sodium hydroxide)	500mg	1000ppm	2 hours	10	80°c	50%
147	Sulphuric acid treated ginger waste (TGW) powder adsorbent	20mg	50ppm	180 minutes	9.5	30°c	50%
148	Walnut shell powder (WNS) adsorbent	0.5g	300ppm	400 minutes	7.5	30°c	50%
149	Sauropus androgynus modified using sodium hydroxide used as an adsorbent	0.05g	25ppm	120 minutes	12	60°c	50%
150	Yeast-treated peat adsorbent	0.05g	25ppm	30 minutes	3.2	60°c	48%
151	Bentonite modified with sodium carbonate and fatty acid used as adsorbent	0.5g	800ppm	180 minutes	6	25°c	40%
152	Kaolin clay adsorbent	0.1g	5ppm	30 minutes	10	30°c	40%
153	Spent tea leaves (STL) powder adsorbent	0.01g	50ppm	1 hour	8	50°c	37%

154	<i>Gliricidia sepium tree</i> Woody biochar adsorbent	2g	25ppm	4 hours	8	30°c	20%
155	Black tea leaves powder (BTL)	0.05g	25ppm	6 hours	6	30°c	≈15%



## CONCLUSION

150 research papers with various low-cost adsorbents obtained from agricultural, industrial and other waste materials as well as novel adsorbents like nano and bio waste adsorbents used for the removal of crystal violet dye from aqueous solution/industrial effluents by adsorption technique were collected.

The following conclusions arrived after thoroughly going through the research articles collected

- ✧ Removal percentage of crystal violet dye increased with decrease in concentration of dye solution due to the availability of more number of active sites on the surface of the adsorbents for adsorption of less number of dye species due to low concentration of the dye solution
- ✧ As the dosage of the adsorbent increases the removal percentage of the dye also increases due to the greater surface area available for the adsorption of more number of dye species
- ✧ Smaller the particle size, greater is the surface area available for adsorption, therefore removal percentage of crystal violet dye increases with decrease in the particle size of the adsorbent
- ✧ pH plays an important role in the adsorption process. The adsorption of crystal violet dye was found to be favorable either at normal pH or in alkaline pH as per the results revealed by the research papers


The adsorbents with very high adsorption efficiency (99%) in the removal of crystal violet dye from aqueous solution includes :

### Agricultural waste adsorbents

- ✧ Mango leaves biochar (MLBC) adsorbent
- ✧ *Artocarpus heterophyllus* (jackfruit) leaf powder (JLP) adsorbent
- ✧ *Syzygium cumini* seed acid activated carbon adsorbent
- ✧ Palm oil shells activated carbon coated with Fe<sub>3</sub>O<sub>4</sub> adsorbent
- ✧ *Tectona grandis* sawdust (TGSD) powder adsorbent
- ✧ Ground rice straw citric acid activated adsorbent
- ✧ Coniferous pinus bark powder (CPBP) adsorbent

### Novel adsorbents

- ✧ An anionic surface modified with neutral alumina surfactant adsorbent
- ✧ Bamboo based lignin (LBM) bamboo fabrics adsorbent
- ✧ *Rhizophora mucronate* activated carbon adsorbent
- ✧ Montmorillonite clay adsorbent
- ✧ Crosslinked grafted xanthan gum copolymer adsorbent
- ✧ Black turmeric rhizomes ash adsorbent .



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