CHAPTER 4
Adsorption Study of Charcoal - from an Agricultural Waste Material - *Limonia Acidissima*

Section I  Removal of Heavy Metals utilizing Activated Charcoal

Section II  Adsorption capacity of Dye

Publications

- “Removal of Methylene Blue from Aqueous Solution Using Biosorbent”
  Der Pharma Chemica, 2010, 2(3), 171-177

- “Biosorption of Lead Ions from Aqueous Solution using Agricultural Waste Material - *Limonia Acidissima*”
4.1 Introduction

Charcoal and Ayurveda

In Ayurvedic system of medicine, activated charcoal is known as one of the finest natural adsorbent agent. Each particle contains many small chambers and cavities that bind up unwanted material or gas. Activated charcoal is used to absorb digestive gas and toxins including poisons. Activated charcoal is mentioned in the Pharmacopoeia like U.S.P. Poison Control Center of U. S. recommends this in the cases of poisoning. Charcoal is the better adsorbent in respect of phenobarbitone and salicilates. It is reported that active carbon is preferred in the treatment of acute poisoning.

In the past, charcoal biscuits were sold in England in the early 19th century, as an antidote to flatulence and stomach trouble. Tablets of activated charcoal are still used as a folk remedy and over-the-counter drug to treat diarrhea, indigestion and flatulence. There is evidence of its effectiveness as a treatment for irritable bowel syndrome and to prevent diarrhea in cancer patients. It is used for bowel preparation by reducing intestinal gas content before abdominal radiography to visualize bile, pancreatic and renal stones. Charcoal tablets help to prevent flatulence by absorbing gases.

Activated *Limonia acidissimia* (bael) charcoal act as buffer antacid, adsorbent and an antidote. It is also used to adsorb gases in the treatment of flatulence and intestinal distension. The pulp of bael contains mucilage pectin and tannin. This mucilage protects gastric mucosa from further acid pepsin assault. Tannin has an astringent action on the mucous membrane of the gastrointestinal tract. Tannin decreases the secretion of hydrochloric acid by its astringent properties and becomes helpful in the case of hyperacidity due to chronic amoebiasis or fermentative acidity. Oxygen carried by the charcoal converts an aerobic form of fermentation. In this way the toxins and offensive bodies produced by the anaerobic bacteria get oxidized. Charcoal is also used in hepatitis B antigen test, which was found to be the quick test.

Literature survey revealed that the isolation and separation of ethanol extract prepared from one of the species of Ehretia, *Ehretia aspera*, failed to yield the
pure constituents by performing neutral alumina or silica gel as adsorbents. However, extraction of partially impure fraction with ethyl acetate using charcoal yielded crystalline alkaloid on standing overnight at room temperature\textsuperscript{7}. The efforts were made towards the separation of the constituents of \textit{Ehretia laevis} using activated fruit shell charcoal of \textit{Limonia acidissima}.

4.1.1 Botanical Characterization and Distribution

\textit{Limonia Acidissima}, family Rutaceae, is the only species within the monotypic genus Limonia. It is a small tree growing to nine meter tall, with rough, spiny bark. The leaves are pinnate; fruit is a berry five to nine cm diameter and may be sweet or sour. It has a very hard rind which can be difficult to crack open and contains sticky brown pulp and small white seeds. It is native to India, Pakistan, Sri Lanka and Java.

4.1.2 Classification

Kingdom Plantae
Sub Kingdom Tracheobionta
Superdivision Spermatophyta
Division Magnoliophyta
Class Magnoliopsida
Subclass Rosidae
Order Sapindales
Family Rutaceae
Genus Limonia L
Species \textit{Limonia acidissima}

4.1.3 Present Work

The fruit shell of \textit{Limonia Acidissima} was collected from nearby area of Pune, Maharashtra, India. It was identified and authenticated at Botanical Survey of
Raw material was dried, crushed and powdered (PRM). The uniform particle sized (63 mesh) material was used to achieve all experiments as an adsorbent.

The material (100g) was treated with A. R. grade concentrated H₂SO₄ (70 ml) and kept at 120°C for a period of six hours. The carbonized material was then washed with distilled water to remove the free acid and dried at 105°C. The dried activated charcoal (AC) was grounded and sieved to get uniform size (63 mesh) and used as an adsorbent. The physicochemical properties of PRM and AC are summarized (Table 1). All tests were conducted under similar sets of conditions and the results were compared for better adsorbing capacity of test samples.

Table 1: Physicochemical Properties of PRM and AC Adsorbents

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Characteristic Values</th>
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<tbody>
<tr>
<td></td>
<td>PRM</td>
</tr>
<tr>
<td>pH</td>
<td>7.00</td>
</tr>
<tr>
<td>Moisture</td>
<td>6.17 %</td>
</tr>
<tr>
<td>Bulk density (g /ml)</td>
<td>0.377 g/ml</td>
</tr>
<tr>
<td>Water soluble matter (%)</td>
<td>7.88 %</td>
</tr>
<tr>
<td>Acid soluble matter (%)</td>
<td>12.10 %</td>
</tr>
<tr>
<td>Ash content</td>
<td>3.08 %</td>
</tr>
<tr>
<td>Iron Content</td>
<td>0.94 %</td>
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</table>
Surface Morphology:
The pore structure in both raw material and also activated carbon was observed by using Scanning Electron Microscope (SEM). Fig. 1a and 1b revealed changes in surface morphology of raw material as it underwent both physical and chemical carbonization. The activated carbon showed high porosity compared to raw material. This was due to carbonization process of raw material, obtained by using concentrated H₂SO₄. Volatile matter was lost and thus created a system with advanced pore structure. Pores development in an activated carbon is important since pores act as active sites which played the main role in adsorption. Pores formed on surface of adsorbent are the sites for metal to be adsorbed onto the adsorbent.

Fig 1: Pore Structures

(a) Powdered Raw Material

(b) Activated Charcoal
Section I Removal of Heavy Metals utilizing Activated Charcoal

4.2.1 Introduction

The presence of heavy metals in the environment posses a serious and complex pollution problem that has been and still is a focus of attention all over the world. Heavy metals are among the main pollutants of surface and groundwater. The environmental impact due to their toxicity has led to the enforcement of stringent standards for the maximum allowable limits of their discharge into open landscapes and water bodies. Lead pollution in water has been increasing progressively in India. This gives rise to concern over health problems in human being and animals. Therefore, it is of great relevance to develop a new method for its removal.

Today contamination of ground water is a major concern in the management of water resources. In the present study lead and cadmium have been selected because of their environmental importance related to its well known toxicity and intensive use in industries. Lead and cadmium are the heavy metals, which are highly toxic to humans, plants and animals. The metals are of special concern due to their non-biodegradable and therefore persistent nature. Assimilation in the human body of relatively small amounts of lead over a long period initiates malfunctioning of certain organs and chronic toxicity. Toxicological effects of the acute cadmium poisoning are manifested in a variety of symptoms, including high blood pressure, kidney damage and destruction of red blood cells.

The major sources of lead and cadmium, release into the environment, by waste stream are electroplating, smelting, alloy manufacturing, pigments, plastic, battery, mining, refining processes, dyes, textile operations etc. Contaminant as heavy metals are characterized by a variety of processes occurring in the soil.

Many methods of treatment for industrial waste water have been reported in literature. Most conventional waste water treatment techniques such as
filtration, flocculation, reverse osmosis, chemical precipitation or coagulation, ion-exchange, ultra filtration and chemical deposition require high capital and operating costs and may produce large volumes of wastes\textsuperscript{17, 18}. Therefore, the above mentioned techniques are not economically feasible for small and medium industries. Adsorption processes using agricultural waste products as biosorption are becoming the new alternative for waste water treatment. According to Kargi and Cikla\textsuperscript{19}, biosorption process is much superior to chemical and physical methods due to the following factors:

- Excess sludge generated from waste water treatment plants can used as Biosorbent
- Biosorbent are cheaper, easily available and reusable.
- Selective adsorption of metal ions can be achieved using biosorbents
- High adsorption capacity.
- Biosorption process can be operated over broad range of environmental conditions such as pH, ionic strength and temperature.

The presence of copper, zinc, lead, cadmium, iron, nickel and other metals have a potentially damaging effect on human physiology and other biological systems when the tolerance levels are exceeded. For low concentrations of metal ions in wastewater, the adsorption process is recommended for their removal. The process of adsorption implies the presence of an “adsorbent” solid that binds molecule by physical attractive forces, ion exchange and chemical binding.

Commercial carbon is the most commonly used adsorbent in the adsorption process for the treatment of wastewater\textsuperscript{20} but metal ion removal by adsorption with this carbon is relatively expensive. Due to the high cost of commercial carbon and 10-15% loss during regeneration, alternative low cost adsorbents have attracted the attention of several investigators to provide an alternate for the high cost commercial carbon. The process for removing metal ions from aqueous solutions by different activated carbon obtained from agricultural by-products has been reported\textsuperscript{21, 22}. In recent years considerable attention has been devoted to the study of removal of heavy metal ions from solution by adsorption using agricultural materials. Natural
materials that are available in large quantities or certain waste from agricultural operations may have potential to be used as low cost adsorbents, as they represent unused resources, widely available and are environmentally friendly.

4.2.2 Review of Literature

Some previous investigations on the removal of heavy metal ions with many agricultural byproducts have been reported. The increase in industrial activities has caused many water bodies receiving loads of heavy metals that exceed the maximum permissible limit for wastewater discharge designed to protect the environment, human and animals from aqueous solution. Pollution by heavy metal ions, including lead Pb and Cadmium Cd have become major issue throughout many countries due to their toxic effects. The risk of Pb(II) can bioaccumulate through the food chain. These metals cannot be destroyed as such but can be removed from water bodies.

Conventional methods for the removing of heavy metals include filtration, chemical precipitation and ion exchange, electrochemical deposition and membrane process. However, these methods are either inefficient or expensive especially when the concentration of the heavy metal ion is low, in the range of 1-100 mg/L.

Previous studies on the use of various agricultural wastes such as rice husks and wheat hulls, groundnut shells, palm oil shells and physic nut wastes as raw material source of activated carbon showed that the preparation cost of activated carbon can be reduced if such waste materials have been used.

4.2.3 Present work

The effectiveness of adsorption of lead and cadmium by activated carbon, prepared from fruit shell of Limonia Acidissima, was studied to determine the maximum adsorption capacity of lead and cadmium by batch mode process.
L. Acidissima, agricultural by-product, can be employed as heavy metal adsorbent. Literature survey does not give any information for metal removal. In this study the capabilities of L. Acidissima for lead and cadmium ion adsorption were tested at various experimental conditions, such as pH, contact time and temperature of the solution. The study was performed to optimize the conditions to be utilized on a commercial scale for the decontamination of effluents. The equilibrium data is described by Freundlich and Langmuir adsorption isotherms.

4.2.4 Results and Discussion

The capacity of adsorption of Pb (II) and Cd (II) from effluents by this prepared activated charcoal under various conditions has been executed for the first time. The time dependent behavior of Pb (II) and Cd (II) adsorption were measured by varying the temperature and pH of the solution.

4.2.4.1 Lead

Effect of Temperature: The time-dependent behaviour of Pb (II) adsorption is measured by varying the equilibrium time between adsorbate and adsorbent in the range of 1 - 180 min. The concentration of Pb (II) is kept as 35 mg/50ml while the amount of adsorbent is 1 g. The percentage adsorption of Pb (II) by using PRM and AC are plotted (Fig 2a and 2b) as a function of contact time with temperature. Results indicate that the equilibrium between the Pb (II) and adsorbent is attained after 60 min. Therefore, a 60 min shaking time was found to be appropriate for maximum adsorption for both test samples.

In case of PRM, adsorption is 51 percent at 25°C while at 35°C and 45°C it becomes 39 and 38 percent. This shows the decrease in adsorption with increase in temperature. This signifies that PRM can be used as adsorbent only at lower temperature.

In the case of AC, with increase in temperature substantial increase in percent adsorption is observed. This is pointing out that the process is endothermic. These experiments indicate that the adsorption increase enormously from 25°C to 45°C. The results noted for adsorption as 68 %
to 92%. This enhancement in adsorption may be due to an increase in the pore size with rise in temperature (25°C to 45°C).

In the case of (PRM) adsorption capacity is 13, 10 and 10 mg/g while in the case of (AC) it is 18, 24 and 24 mg/g at temperatures 25°C, 35°C and 45°C respectively. Results are indicated that the adsorption capacity of activated charcoal is more than the powdered raw material (Fig 3 a and 3b).

**Adsorption Isotherms:**

The equilibrium sorption isotherms are fundamentally important in designing biosorption process (Fig 4 and 5). The experimental isotherm data is analyzed to check the applicability using Freundlich and Langmuir model to explain the adsorption. The value of correlation coefficient R^2 obtained from linear plot of Freundlich and Langmuir isotherm are very close to unity which indicate the applicability of these model.

**Effect of pH:**

At low pH the concentration of protons is high and metal binding sites become positively charged repelling the Pb (II) and Cd (II) cations. With an increase in pH, the negative charge on the biocarbon increases due to which the metal ion bind to the active sites, resulting in the increasing capacity of metal biosorption. Results are recorded (Fig 6a,6b and 7a,7b).

**Fig 2 Effect of Temperature on % Adsorption of Pb^{2+} with respect to Time**

(a) PRM  
(b) AC

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Fig 3 Effect of Temperature on Adsorption Capacity of Pb\(^{2+}\) with respect to Time

(a) PRM

(b) AC

Fig 4 Freundlich Isotherm

Freundlich Isotherm

\[ y = 4.790x - 11.00 \]

\[ R^2 = 0.916 \]

Fig 5 Langmuir Isotherm

Langmuir Isotherm

\[ y = 0.017x \]

\[ R^2 = 0.956 \]

Fig 6 Effect of pH on % Adsorption of Lead using AC and PRM
Fig 7 Effect of pH on Adsorption Capacity of Pb\(^{2+}\) With Respect to Time

<table>
<thead>
<tr>
<th>Material</th>
<th>Charcoal</th>
</tr>
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<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

4.2.4. II Cadmium

Effect of Temperature

The time-dependent behaviour of Cd (II) adsorption is measured by varying the equilibrium time between adsorbate and adsorbent in the range of 1 - 180 mins. The concentration of Cd (II) is kept as 35mg/50ml while the amount of adsorbent is 1 g. The percentage adsorption of Cd (II) by using PRM and AC are plotted (Fig 8a and 8b) as a function of contact time with temperature. Results indicate that the equilibrium between the Cd (II) and adsorbent is attained after 60 min. Therefore, a 60 min shaking time was found to be appropriate for maximum adsorption for both the test samples.

The powdered raw material PRM indicates that with increase in temperature there is increase in percent adsorption. This signifies that (PRM) can be used as adsorbent at high temperature also.

The activated charcoal AC indicates that with increase in temperature substantial increase in percent adsorption is observed. This enhancement in adsorption is due to an increase in the pore size with rise in temperature from 25°C to 45°C.

Results indicate that the adsorption capacity of activated charcoal is more than the powdered raw material (Fig 9a and 9b).
**Adsorption Isotherms:**
The experimental isotherm data is analyzed using Freundlich and Langmuir isotherm (Fig 10 and 11). The value of correlation coefficient $R^2$ obtained from linear plot of both is very close to unity which indicates the applicability of these models.

**Effect of pH:**
Adsorption of metal cation on adsorbent depends upon the nature of adsorbent surface and species distribution of the metal cation. Surface distribution mainly depends on the pH of the system. In the case of activated charcoal the percent adsorption and adsorption capacity is more than powdered raw material. The results are depicted (Fig 12 and 13).

**Fig 8 Effect of Temperature on % Adsorption of Cd^{2+} with respect to Time**

![Fig 8](image-url)

(a) PRM

(b) AC
Fig 9 Effect of Temperature on Adsorption Capacity of Cd\(^{2+}\) With Respect to Time

(a) PRM

(b) AC

Fig 10 Freundlich Isotherm

\[ y = 1.202x + 0.247 \]
\[ R^2 = 0.899 \]

Fig 11 Langmuir Isotherm

\[ y = 25.15x + 1.796 \]
\[ R^2 = 0.966 \]
Fig 12 Effect of pH on % Adsorption of Cadmium using Charcoal and Material
(a) PRM  (b) AC

Fig 13 Effect of pH on Adsorption Capacity of Cadmium using Charcoal and Material
(a) Powdered Raw Material  (b) Activated Charcoal
4.2.5 Conclusion

At higher pH both metals were precipitated due to the formation of hydroxides and removal due to sorption was very low. At low pH the concentration of protons is high and metal binding sites become positively charged repelling the Pb(II) and Cd(II) cations. With an increase in pH, the negative charge on the biocarbon increases due to which the metal ion bind to the active sites, resulting in the increasing capacity of metal biosorption.

The greater environmental awareness in both the public and regulatory sphere in recent years has necessitated greater treatment of industrial effluent. As such there has been a great deal of research into finding cost-effective methods for the removal of contaminants from wastewater. Result from this study shows that Pb(II) and Cd(II) can be highly adsorbed by the activated charcoal while the removal percentage of Cd (II) is low. This study may generate useful information for the utilization of native agricultural by-products for the removal of lead and cadmium from wastewater. Use of this activated carbon is not only effective for Pb (II) removal from aqueous water but also helps in solving the problem of over-abundance of fruit shell of L. Acidissima as agricultural waste product.

4.2.6 Experimental

Adsorption experiments were performed using powdered raw material (PRM) and activated charcoal (AC). Standard solutions of Pb (II) and Cd (II) were prepared as 500,700,900 mg/lit. To this standard solution (50ml), distilled water (50ml) and adsorbent (1g) was added, stirred at regular time interval. This was filtered and amount of lead, cadmium in the filtrate was determined by titrating against standardized EDTA solution. The effect of contact time, temperature and pH of the solution was studied.

The proportion of heavy metal removed from solution was calculated from \((C_0 - C_e)\) where \(C_0\) and \(C_e\) are respectively, the initial and final concentrations of heavy metal. The amount of adsorbed metal ions per unit mass of biocarbon was obtained from \(q_e = \frac{x}{m}\), where \(x\) is \((C_0 - C_e)\) \(v\) and \(v\) is the volume of the medium and \(m\) is the mass of biocarbon used.
Section II

Adsorption capacity of Dye

4.3.1 Introduction

Dyes are used as colouring matter by the industries. The unspent colouring materials are discharged into the aquatic environment and therefore are considered to be one of the important visible pollutants of industrial waste water. Dyes are highly coloured compounds which are non biodegradable. These dyes persist in water, which retards photosynthetic activity, inhibit growth of aquatic biota and decrease recreation value of stream. Methylene blue is an important basic dye used for printing calico, dyeing cotton and leather. It is not strongly hazardous but has various harmful effects, such as eye burns, irritation to the gastrointestinal tract and to the skin. Therefore, it is necessary to remove methylene blue from waste water. The reports revealed that the removal of dye can be achieved by chemical coagulation, ozonation, membrane filtration, ion-exchange, precipitation and adsorption. Among these, adsorption is the most effective and economical method. Activated carbon has been the most effective adsorbent for the removal of various pollutants from waste water. This is due to its highly porous nature, large surface area to volume ratio and presence of surface functional groups. The high cost of activated carbon however, restricts its application in developing countries including India. This has promoted a growing research interest into the production of low – cost alternatives to activated carbon.

4.3.2 Review of Literature

Adsorption has been found to be superior to other techniques for wastewater treatment in terms of initial cost, simplicity of design, ease of operation and insensitivity to toxic substances. Activated carbon, AC is a form of carbon that is specially treated to produce a highly developed internal pore structure and a large surface area, thus, producing reasonably cheap and excellent adsorbent.
There is a multitude of industrial applications of activated carbon. Pollution control and wastewater treatment are growing areas of use to combat environmental pollution\textsuperscript{42-45}. Some agro waste materials had been used as adsorbent for dye sorption from wastewater are listed in Table 2.

**Table 2: Materials Used for Removal of Dyes**

<table>
<thead>
<tr>
<th>Adsorbent(s)</th>
<th>Dye(s)</th>
<th>References</th>
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<tbody>
<tr>
<td>Jackfruit peel</td>
<td>Methylene blue</td>
<td>46</td>
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<tr>
<td>Jackfruit leaf</td>
<td>Methylene blue</td>
<td>39</td>
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<tr>
<td>Cotton fibre</td>
<td>Methylene blue</td>
<td>47</td>
</tr>
<tr>
<td>Sugarcane bagasse</td>
<td>Methyl red</td>
<td>48</td>
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<tr>
<td>Rice husk, groundnut shell, coconut shell, Bamboo dust</td>
<td>Methylene blue</td>
<td>49</td>
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<tr>
<td>Indian Rose Wood Sawdust</td>
<td>Methylene blue</td>
<td>50</td>
</tr>
<tr>
<td>Oil palm trunk fibre</td>
<td>Malachite green</td>
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</tr>
<tr>
<td>Yellow passion fruit peel</td>
<td>Methylene blue</td>
<td>52</td>
</tr>
<tr>
<td>Rice husk</td>
<td>Malachite green</td>
<td>53</td>
</tr>
<tr>
<td>Banana pith</td>
<td>Congo red, Rhodamine-B, Procion orange</td>
<td>54-58</td>
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<tr>
<td>Guava leaf powder</td>
<td>Methylene blue</td>
<td>59</td>
</tr>
<tr>
<td>Groundnut shell</td>
<td>Malachite green</td>
<td>60</td>
</tr>
<tr>
<td>Rice husk</td>
<td>Methylene blue</td>
<td>61</td>
</tr>
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</table>

### 4.3.3 Present work

The aim of the present study was to determine the optimum conditions for the removal of a cationic dye that is methylene blue, from aqueous solution by adsorption technique using sulphuric acid treated fruit shell.
In this study, the waste fruit shell of *L. Acidissima* was used as a Biosorbent and was tested at various experimental conditions, such as contact time, concentration and temperature of the solution to optimize the conditions to be utilized on a commercial scale for the decontamination of effluents. The powdered raw material and activated charcoal of specific micron size was used for the removal of the methylene blue from aqueous solution. The applicability of this treated material and raw material as an adsorbent for organic pollutant removal was then evaluated and compared using methylene blue at three temperatures and five concentrations.

### 4.3.4 Results and Discussion

**Effect of Initial Dye Concentration with respect to time:**

The experiment was carried out at room temperature by verifying contact time and dye concentration using PRM and AC. The powdered raw material PRM indicates that with increase in dye concentration there is decrease in percent adsorption. The activated charcoal AC indicates that with increase in dye concentration substantial decrease in percent adsorption is observed. The result shows that with increase in dye concentration there is decrease in percentage of adsorption. By comparing percent adsorption of PRM and AC, it is observed that percent adsorption of AC is far more than percent adsorption of PRM. The results are recorded (Table 14 and 15). The amount of dye adsorbed remained constant after equilibrium time (60 minutes).

**Effect of Temperature:**

Temperature is one of the factors that influence sorption process. To determine the effect of temperature, experiments are performed at 25°C, 35°C and 45°C. The results indicate that the adsorption of PRM and AC increases with increase in temperature. Adsorption of PRM is less than adsorption of AC. The amount of dye adsorbed in initial dye concentration and remained constant after equilibrium time (60 minutes).
4.3.5 Conclusion

The result shows that the removal of dyes by chemically treated material is effective than raw material at higher temperature. The percentage removal of dye is maximum at 35°C temperature and at 25°C temperature for raw material.

4.3.6 Experimental

Preparation of adsorbent

The fruit shell charcoal of _L. Acidissima_ was prepared as mentioned in section 4.1.3.

Preparation of dye solution

The solutions of methylene blue (MB), 1 x 10^{-5} M to 5 x 10^{-5} M were prepared.

Adsorption study:

To evaluate the efficiency of adsorbents, laboratory batch mode studies were conducted at different temperatures. In each adsorption experiment, 50 ml of dye solution of known concentration at initial pH of solution was added into 0.050gm of adsorbent in a 100 ml flask and the mixtures was stirred at 500 rpm on a mechanical stirrer. After predetermined time intervals, adsorbent was separated from solution by filtration method. The absorbance of the supernant solution was estimated to determine the residual dye concentration at 660 nm with Spectrophotometer (EQ-65G- A EquipTronics).

The experiment was performed in triplicates and the mean absorbance was taken to determine the residual dye concentration.

Effect of contact time and initial dye concentration

In order to study the effect of initial dye concentration and contact time on equilibrium sorption of MB, 50 ml solution of MB (20, 30, 40 and 50 mg/L MB concentration) was stirred with 0.200 gm biosorbent individually for various intervals of time (from 2 to 120 minutes) at their natural pH of solution. The flasks were agitated at 200 rpm using a mechanical stirrer at room temperature (25 ± 2 °C). The sorbent and sorbate solutions were separated
by gravity separation. The supernatant solutions were analyzed for the residual concentration of MB spectrophotometrically at 620 nm wavelength. (UV – Vis S1700 Pharma spectrophotometer, Schimadzu).

**Effect of temperature**

To determine the effect of temperature, sorption studies of MB were performed at three different temperatures, i.e., 25, 35 and 45 °C, by shaking 0.050 gm of sorbent with 50 ml solution of known concentration of MB (3.7 mg/L) individually at various intervals of time (2 to 120 minutes).

**Fig 14** Effect of Concentration on % Adsorption of AC

![Effect of Concentration on % Adsorption of AC](image)

**Fig 15** Effect of Concentration on % Adsorption of PRM

![Effect of Concentration on % Adsorption of PRM](image)
Fig 16  Effect of Temperature on % Adsorption of AC

![Graph showing the effect of temperature on % adsorption of AC.]

Fig 17  Effect of Temperature on % Adsorption of PRM

![Graph showing the effect of temperature on % adsorption of PRM.]

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