

Production Of Activated Carbon From Agricultural Raw Waste

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Abstract: Our project is on resource assessment of raw materials show there is more than enough of the agricultural waste raw material available for activated carbon production to meet local demand. In view of these facts, we proposed to do project in the area of study in activated carbon. Activated carbon is used in gas purification, decaffeination, gold purification, metal extraction, water purification, medicine, sewage treatment, air filters in gas masks and respirators, filters in compressed air and many other applications. Due to its high degree of micro porosity, just one gram of activated carbon has a surface area in excess of 500 m², as determined by gas adsorption. An activation level sufficient for useful application may be attained solely from high surface area; however, further chemical treatment often enhances adsorption properties. One major industrial application involves use of activated carbon in the metal finishing field. It is very widely employed for purification of electroplating solutions. For example, it is a main purification technique for removing organic impurities from bright nickel plating solutions. Projecting on the available raw materials, it is established that industrial demand for activated carbon can be met locally. The characterization of two types of factory wastes showed that paper waste was a better option over rice husk. The activated carbon produced from pyrolysis of paper mill waste was chemically activated with various activating agents like zinc chloride, potassium hydroxide and potassium chloride. A systematic investigation of the effect of impregnation ratio, activation temperature and activation time on the properties of the activated carbon was done. The optimum preparation conditions together with the effected of these conditions on the yield and efficiency of produced AC have been studied. The chemically activated carbons were characterized by measuring iodine and yield percentage. The activated carbon prepared from paper mill waste in this study had maximum iodine of 764.80 mg/g with ZnCl₂ as the activating agent.

Keywords: Production, Activated Carbon, Agricultural, Raw Waste

I. INTRODUCTION

Activated carbon, also widely known as activated charcoal or activated coal is a form of carbon which has been processed to make it extremely porous and thus to have a very large surface area available for adsorption or chemical reactions. The word active is sometimes used in place of activated. Due to such high degree of micro porosity, just 1 gram of activated carbon has a surface area in excess of 500 m² (about one tenth the size of an American football field), as typically determined by nitrogen gas adsorption. Sufficient activation for useful applications may come solely from the high surface area, though further chemical treatment generally enhances the adsorbing properties of the material. Activated carbon is most commonly derived from charcoal.

1.1 Preparation of activated carbon:

Activated carbon is nothing but carbon produced from carbonaceous source materials like nutshells, peat, wood, coir, lignite, coal and petroleum pitch. It can be produced by any one of the following described processes:

- Physical reactivation: by this process precursor is developed into activated carbons using gases. This is generally done by using one or a combination of the following processes
- Carbonization:* Material having appreciable carbon content is pyrolyzed at temperature ranging between 600–900 °C, in the absence of oxygen (usually in inert atmosphere with gases like argon or nitrogen)

Activation/Oxidation: in this process raw material or carbonized material is exposed to oxidizing atmospheres (carbon monoxide, oxygen, or steam) at temperatures above 250 °C, usually in the temperature range of 600–1200 °C.

- Chemical activation: Before carbonization, the raw material can be impregnated with certain chemicals. The chemical needs to be typically an acid, strong base, or a salt phosphoric acid, potassium hydroxide, sodium hydroxide, zinc chloride, respectively). After impregnation, the raw material needs to be carbonized at lower temperatures (450–900 °C). It is believed that the carbonization / activation step proceeds simultaneously with the chemical activation. Chemical activation is preferred over physical activation owing to the lower temperatures and shorter time needed for activating material

1.2 Objective of the project:

Different surface analyses are to be used in this study to evaluate the effect of production processes on the physical characteristics of the produced carbons. The significant feature of waste-based activated carbon that makes it a unique and a particularly economical adsorbent is that it can be produced from waste materials such as paper mill waste or even the rice husk disposed of as waste from rice mills. A current problem faced by pulp mills is the generation of an excessive amount of waste during the paper making process and secondary treatment of wastewater. For environmental and ecological reasons, the innocuous disposal of these wastes has become immensely important.

Optimization of the processes involved with the conversion of paper mill waste or rice husk to activated carbon provides an innovative, environmentally safe, and economically feasible solution to the problem of waste management at paper mill facilities. Waste to carbon conversion processes can significantly reduce the waste volume produced in the paper mill industry or the rice mills, eliminate the need for further treatment of waste, reduce the cost of hauling and land filling the waste, and reduce transportation costs. A comparison between physical and chemical preparation methods and their efficiency were investigated. Results are shown that the preparation by chemical method is more efficiency than physical method due to bigger surface area of AC, except treatment with NaOH.

The emphasis of this study is to optimize processes involved with the production of activated carbons with prescribed surface properties (micro- or meso porous structure) and specific end uses from paper mill waste. The higher purity (when compared to bio-solids), negative cost, high rate of production, and strong carbonaceous structure of paper mill waste and rice husk makes them both useful as a precursor for carbon production.

II. PRECURSOR SELECTION

2.1 Precursor Selection

Precursor (raw material) selection for the production of activated carbon was obviously the first step of the project. Conventionally, activated carbon is produced from carbonaceous source material such as wood, peat, coal, and wastes of vegetable origin (e.g. nutshells, fruit stones). Today, one promising approach for the production of cheap and efficient activated carbon is the reuse of waste waste, such as bio solids produced at municipal or factory wastewater treatment facilities. The usage of waste waste is especially important due to its mass production and resulting occupation of valuable landfill space.

The two types of factorywaste available as choices for precursor were:

- Rice husk (Bargarh paper mill)
- Paper waste (JK paper mill, Rayagada)

To decide the superiority of a precursor over the other characterization of the precursor was done using various methods like:

- CHNS elemental analyser
- Proximate analysis

2.2 CHNS elemental analyser

CHNS elemental analysers provide a means for the rapid determination of carbon, hydrogen, nitrogen and sulphur in organic matrices and other types of materials. They are capable of handling a wide variety of sample types, including solids, liquids, volatile and viscous samples, in the fields of pharmaceuticals, polymers, chemicals, environment, food and energy. The analysers are often constructed in modular form such that they can be set up in a number of different configurations to determine, for example, CHN, CHNS, CNS or N depending on the application. This adaptability allows not only flexibility of operation but also the use of a wide range of sample weights from a fraction of a milligram to several grams (macro-systems.) In its simplest form, simultaneous CHNS analysis requires high temperature combustion in an oxygen-rich environment and is based on the classical Pregl-Dumas method. This combustion can be carried out under both static conditions i.e. introduction of a set volume of oxygen or dynamic conditions i.e. a constant flow of oxygen for a set period of time. Often, catalysts are also added to the combustion tube in order to aid conversion. In the combustion process (furnace at ca. 1000 C), carbon is converted to carbon dioxide; hydrogen to water; nitrogen to nitrogen gas/ oxides of nitrogen and sulphur to sulphur dioxide. If other elements such as chlorine are present, they will also be converted to combustion products, such as hydrogen chloride. A variety of absorbents are used to remove these additional combustion products as well as some of the principal elements, sulphur for example, if no determination of these additional elements is required. The combustion products are swept out of the combustion chamber by inert carrier gas such as helium and passed over heated (about 600 C) high purity copper. This copper can be situated at the base of the combustion chamber or in a separate furnace. The function of this copper is to remove any oxygen not consumed in the initial combustion and to convert any oxides of nitrogen to nitrogen gas. The gases are then passed through the absorbent traps in order to leave only carbon

dioxide, water, nitrogen and sulphur dioxide. Detection of the gases can be carried out in a variety of ways including (i) a GC separation followed by quantification using thermal conductivity detection (ii) a partial separation by GC (frontal chromatography) followed by thermal conductivity detection (CHN but not S) (iii) a series of separate infra-red and thermal conductivity cells for detection of individual compounds. Quantification of the elements requires calibration for each element by using high purity micro analytical standard compounds such as acetanilide and benzoic acid.

2.3 Applications of CHNS Elemental Analysers

CHNS elemental analysers have been used in analytical laboratories for over thirty years. The method is used extensively across a wide range of applications, including pharmaceuticals, chemicals, oil-related products, catalysts and food. In the oil industry, an important application is the regular monitoring of coke build-up on refinery catalysts to ensure that regeneration procedures (involving controlled burning of the carbon) are executed at optimal intervals. Since many of these catalyst systems involve large quantities of noble metals such as platinum, palladium and rhenium, mismanagement of this testing would entail serious financial losses. In food analysis, the determination of nitrogen (as a surrogate for protein) is very important for pricing grain and evaluating meat products, and is increasingly undertaken by combustion analysis.

2.4 Proximate Analysis:

The proximate analysis of a substance is a simple means of determining the distribution of products obtained when the coal sample is heated under specified conditions. As defined by ASTM D 121, proximate analysis separates the products into four groups: (1) moisture, (2) volatile matter, consisting of gases and vapors driven off during pyrolysis, (3) fixed carbon, the nonvolatile fraction of coal, and (4) ash, the inorganic residue remaining after combustion. Proximate analysis is the most often used analysis for characterizing a material in connection with their utilization.

Volatile matter:

The sample was measured and placed in a closed crucible. It was then heated upto 925 C for exactly 7.5 min in a furnace. The crucible was then cooled in a desiccator and weighed

Ash content:

Sample was measured and taken in a crucible. It was then heated to 750 C for 1.5 hr. During this test the crucible was left open. After the required heating, the crucible was cooled in a desiccator and then weighed.

Moisture content:

Sample was measured and taken in a petri dish. It was spread nicely on the dish. It was then heated at 105 C for 1.5 hr. the petri-dish was left open during the heating process. After heating petri-dish was removed, cooled in desiccator and then weighed.

III. PREPARATION AND CHARACTERIZATION OF ACTIVATED CARBON

3.1 Preparation of activated carbon :

A pure, mesoporous activated carbon was produced following using following procedure. The prescribed process of production of activated carbon is as below:

Raw waste was first dried in an oven at 110°C for 24 h, then crushed manually. Crushing provided smaller particles with increased surface area and also enabled more efficient chemical activation of the raw material.

- Samples were sieved after crushing to obtain particle sizes smaller than 600 µm.
- Chemical activation of the waste was then done using different activating agents like ZnCl₂, KOH and KCl. To ensure a complete reaction between activating agent and waste particles, slurries of the waste and activating agent were mixed at 85°C for 7 hrs with a magnetic stirrer.
- After chemical activation, samples were dried at 110°C for about 10–36 h (depending on the required impregnation time).
- After drying, the waste was crushed again into a fine powder. And activated samples were exposed to light and humidity (L&H) for about 22 h to enhance the development of the pore structure during pyrolysis. The aforementioned steps promote uniform carbonization reactions during the pyrolysis
- The dried, chemically activated, and light and humidity treated waste was placed into a quartz reactor. The pyrolysis was carried out under a flow of nitrogen gas (70 ml/min) at
- 500-800 °C (depending on the set activation temperature) for 1 to 2 h (depending on the decided activation time). The temperature was reached at a rate of approximately 20 °C per min. Nitrogen gas was used to provide an inert atmosphere and to carry volatile matter away from the heating zone. Upon completion of the pyrolysis, sample was removed from the reactor and crushed using mortar and pestle.
- Upon completion of the pyrolysis, the sample was removed from the reactor and crushed.
- Pyrolysis was followed by rinsing using 500 ml of 1.2 M HCl, and 500 ml of distilled water to remove excess activating agent and residual inorganic matter.

- Then the chemical activated product was dried and stored for characterization.

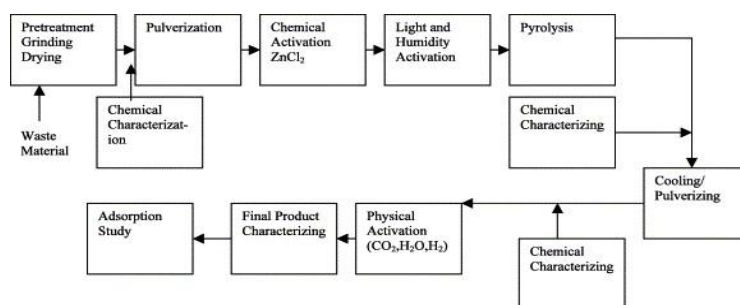


Figure.3.1 Steps involved with the production of activated carbon from paper mill waste.

3.2 Characterization of activated carbon produced:

3.2.1 Iodine value of the activated carbon:

To gain further knowledge of the porous structure of activated carbon, iodine adsorption from liquid phase was adopted by other researchers in the characterization of waste-based activated carbons. The adsorption of aqueous I_2 is considered a simple and quick test for evaluating the surface area of activated carbons associated with pores larger than 1 nm. [54] The iodine value, defined as the amount of iodine adsorbed per gram of activated carbon at an equilibrium concentration of 0.02 N, was measured according to the procedure established by the American Society for Testing and Materials (ASTM 2006). The mean values of data for each experiment were presented. Standard deviation was calculated from triplicate samples. Iodine Number is accepted as the most fundamental parameter used to characterize activated carbon performance. It gives the measure of activity level (higher number indicates higher degree of activation). It indicates the microspore (0 – 20 Å) content. Reagents used in the iodine value test are as listed below:

- 0.1N Iodine solution (40 gm KI in 1 Ltr of Distilled water).
- 0.05N Sodium Thiosulphate solution (12.5 gm $Na_2S_2O_3 \cdot 5H_2O$ in 1 Ltr Distilled water)
- 1% Starch solution
- Activated carbon

3.2.3 Other physical properties of activated carbon:

The apparent density of the material was obtained by weighting five grams of the produced activated carbon and transferring it into a 10 mL graduated cylinder. The cylinder was tamping with a rubber pad while activated carbon was being added until the entire original sample was transferred to the cylinder. Tamping was continued for 5 minutes until there was no further settling produced. The volume was recorded and the apparent density was calculated on the dry basis: Ash content was measured by burning the produced activated carbon in a muffle furnace at 973 K. One gram of dry carbon was transferred into a crucible and then placed in the furnace for four hours. The difference between the original and final weight of the carbon represents the ash content per gram. Moisture content was also obtained by weighing 10 grams of the carbon and placed in an oven at 105 C for 3 h. Then the carbon was cooled in the absence of humidity and reweighed again. The difference between the initial and final mass of the carbon represents the water content in the sample. The yield of activated carbon product was calculated based on the chemical-impregnated waste dried at 105 C. The composition of C, H and N in the activated carbon used as raw material was determined using an elemental analyzer (PE-2400 II, Perkin-Elmer Corp., USA).

3.2.4 X-Ray Diffraction Measurements:

X-ray scattering techniques are a family of non-destructive analytical techniques which reveal information about the crystallographic structure, chemical composition, and physical properties of materials and thin films. These techniques are based on observing the scattered intensity of an X-ray beam hitting a sample as a function of incident and scattered angle, polarization, and wavelength or energy. X-ray diffraction yields the atomic structure of materials and is based on the elastic scattering of X-rays from the electron clouds of the individual atoms in the system. The most comprehensive description of scattering from crystals is given by the dynamical theory of diffraction. Single-crystal X-ray diffraction is a technique used to solve the complete structure of crystalline materials, ranging from simple inorganic solids to complex macromolecules, such as proteins. Powder diffraction (XRD) is a technique used to characterise the crystallographic structure, crystallite size (grain size), and preferred orientation in polycrystalline or powdered solid samples.

3.2.5 Fourier Transform Infrared Spectroscopy:

FTIR is most useful for identifying chemicals that are either organic or inorganic. It can be utilized to quantitate some components of an unknown mixture. It can be applied to the analysis of solids, liquids, and gasses. The term Fourier Transform Infrared Spectroscopy (FTIR) refers to a fairly recent development in the manner in which the data is collected and converted from an interference pattern to a spectrum. Today's FTIR instruments are computerized which makes them faster and more sensitive than the older dispersive instruments. FTIR is commonly used to identify chemicals from spills, paints, polymers, coatings, drugs and contaminants. FTIR is perhaps the most powerful tool for identifying types of chemical bonds (functional groups). The wavelength of light absorbed is characteristic of the chemical bond as can be seen in this annotated spectrum. By interpreting the infrared absorption spectrum, the chemical bonds in a molecule can be determined. FTIR spectra of pure compounds are generally so unique that they are like a molecular "fingerprint". While organic compounds have very rich, detailed spectra, inorganic compounds are usually much simpler. For most common materials, the spectrum of an unknown can be identified by comparison to a library of known compounds. We have several infrared spectral libraries including on-line computer libraries. To identify less common materials, IR will need to be combined with nuclear magnetic resonance, mass spectrometry, emission spectroscopy, X-ray diffraction, and/or other techniques.

3.2.6 Scanning electron microscope analysis:

A scanning electron microscope (SEM) is a type of electron microscope that images a sample by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition, and other properties such as electrical conductivity.

IV. RESULTS AND DISCUSSIONS

4.1 Result of elemental analysis and proximate analysis of the wastes:

From the CHNS analysis and proximate analysis it was clearly seen that there was not much difference in the fixed carbon content. Hence both are viable options for activated carbon production. But the mass per unit volume of paper waste being much higher than that of rice husk, it would be more economical to choose paper waste as the precursor of activated carbon production. Hence paper waste is fixed as our precursor in the further production and analysis of activated carbon.

Table 4.1: Result of elemental analysis of rice

Element	Rice husk (%)	Paper waste (%)
Carbon	38.7	39.52
hydrogen	5	4.53
Oxygen	36	19.22
Nitrogen	.7	.5
Sulphur	.1	.11
Chlorine	0	0.2

Table 4.2. Proximate analysis of the precursor husk and paper waste

component	Rice husk (wt%)	Paper waste (wt%)
Volatile matter	64.7	21.3
Fixed carbon	15.7	50.11
Ash content	19.2	14.5
Moisture content	.4	14.09

4.2 Effect of chemical activating agents on activated carbon produced

In chemical activation, different activating agents are expected to significantly affect the extent of activation.^[55] In the present study, activating with ZnCl₂, KOH and KCl were evaluated and compared. The effect of different activating agents on the iodine value and yield of activated carbon from waste in N₂ atmosphere at 600 C for 1 h calculated. The concentration of various chemical activating agents was fixed at 1 N and the impregnation time for these agents was maintained as 20 h. The iodine values of the activated carbons changed significantly with activating agents. The activation with ZnCl₂ gave the highest yield of 18.4%. More over, the ZnCl₂ activated product had the highest iodine value of 664.8mg/gm, indicating that its pore surface and structure were the best developed. Thus, ZnCl₂ was chosen as the activating agent for subsequent experiments.

4.3 Effect of concentration of ZnCl₂ solution used for producing activated carbons

The yields and iodine values of activated carbons prepared from paper waste in N₂ atmosphere at 600C for 1 h are presented in figure 2. The impregnation process was carried on with various concentrations of ZnCl₂

solution but identical solid waste by dry weight of 6.2 g for a fixed impregnation time of 20 h prior to activation. The iodine values of activated carbons produced had an optimum value of 764.8mg/gm, and the corresponding ZnCl₂ concentration was 2N. When the concentration was decreased to 1 M, the iodine value was relatively low because of insufficient ZnCl₂ to react with the waste to efficiently create the internal pore structures. However, if the concentration of ZnCl₂ was as high as 3N or more, the micropore structure of activated carbon deteriorated due to excessive carbonization. The yield of product decreased steeply from 18.6 to 11.9% in the concentration range with increasing iodine value, which was probably due to the formation of more micropores in the product. The extent of decrease in product yield was lower at higher concentrations of activating agents. In all, we considered the ZnCl₂ concentration of 2 N to be optimum. (Figure.4.1)

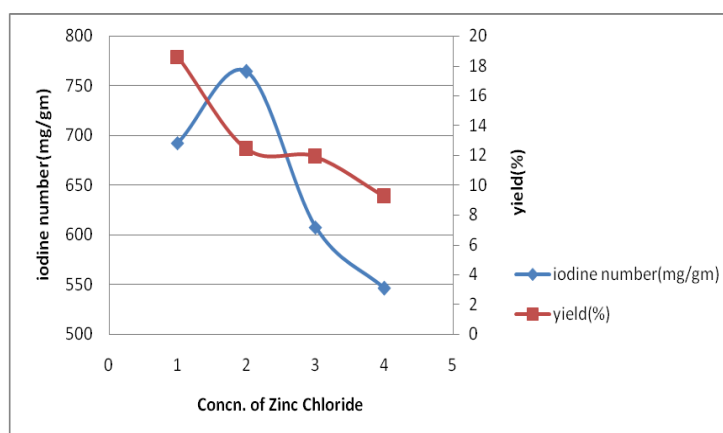


Figure 4.1 Effect of concentration of activating agent on yield percent and iodine value of activated carbon.

4.4 Effect of time of impregnation on activated carbon products

The effect of impregnation time on the iodine value of the activated carbon product was shown in figure 3 . Paper waste was used and activated at 600 C for 1 h. The iodine values of samples increased gradually with time of impregnation, and leveled off after 20 h. Long impregnation time would promote the diffusion of ZnCl₂ in the waste. When the time was extended to 20 h, equilibrium was attained in the mixture of paper waste and ZnCl₂. Hence, the impregnation time of 20 h was required and was used in subsequent experiments. (Figure.4.2)

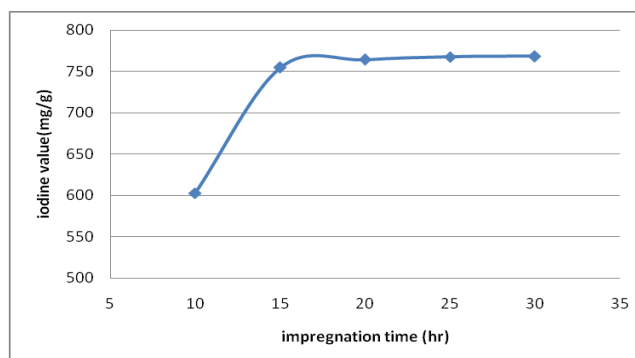


Figure 4.2 Effect of impregnation time on iodine value of activated carbon

4.5 Effect of activation temperature on activated carbon products

The activation temperature is a very influential parameter on the pore structure of activated carbon, which determines the adsorption capacity.^[56] The variation in iodine values of activated carbon product was investigated as a function of activation temperature. Paper waste was used as raw material and activation time was fixed at 1 h. As shown in Figure 4, the iodine value increased progressively with activation temperature, and then decreased when the temperature exceeded 600 C. At higher temperature (.600C), the pore walls between adjacent pores were probably destroyed and the micropores were destructed, which led to the decrease in iodine value of the activated carbon. Thus, it can be concluded that the optimum temperature for the production of activated carbons from paper waste is approximately 600C. (Figure.4.3)

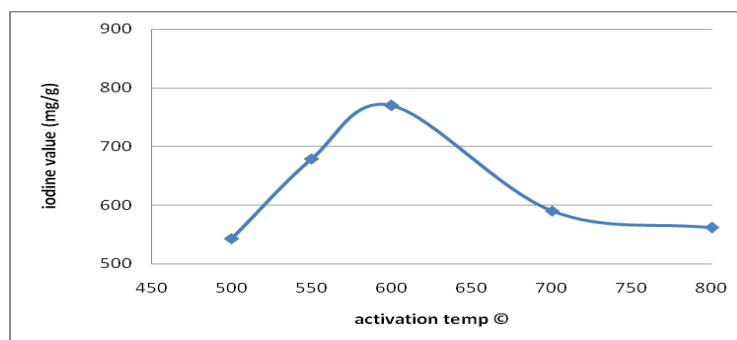


Figure 4.3: Effect of activation temperature on iodine value of the activated carbon

4.6 Effect of activation time on activated carbon products

The variations in iodine value of the activated carbon produced from paper waste versus the activation time are shown in Figure 5. The iodine values were measured as 690.9 and 764.8mg/ g after 30 min and 1 h of activation time, respectively. Thereafter, the iodine value gradually dropped to a value of 574.3mg/gm at 3 h. The decrease in iodine value for the time period of 1– 3 h is considered to be due to the extended activation of product, resulting in the conversion of some micropores into mesopores and mesopores into macro pores. This trend indicates that the activation time of 1 h is optimum in our study. (Figure.4.4)

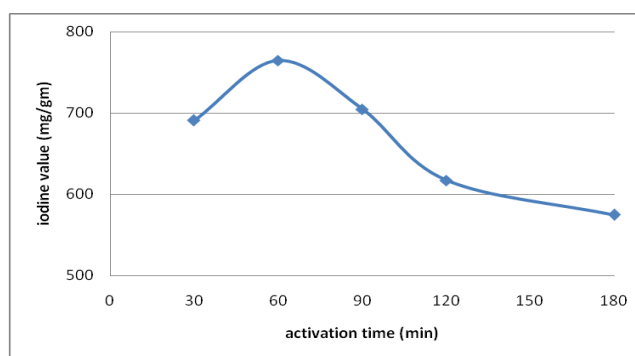


Figure4.4: Effect of activation time on iodine value of activated carbon

4.7 FT-IR analysis:

The FT-IR spectroscopic study of the produced carbon is shown in Figure 4.5. The sample showed four major absorption bands at 2900-3500 cm⁻¹, 1300-1750 cm⁻¹, 1000-1250 cm⁻¹ and 450-750 cm⁻¹. A wide band with two maximum peaks can be noticed at 2930 and 3450 cm⁻¹. The band at 3450 cm⁻¹ is due to the absorption of water molecules as result of an O-H stretching mode of hydroxyl groups and adsorbed water, while the band at 2930 is attributed to C-H interaction with the surface of the carbon. However, it must be indicated that the bands in the range of 3200-3650 cm⁻¹ have also been attributed to the hydrogen-bonded OH group of alcohols and phenols.^{[57],[58]} In the region 1300-1750 cm⁻¹, amides can be distinguished on surface of the activated carbon which has two peaks at 1640 and 1450 cm⁻¹. These functional groups were obtained during the activation process as a result of the presence of ammonia and primary amines that usually exist in the waste. Moreover, the band at 1500 cm⁻¹ may be attributed to the aromatic carbon-carbon stretching vibration. The two peaks at 1125-1150 cm⁻¹ yield the fingerprint of this carbon. The sharp absorption band at 1125 cm⁻¹ is ascribed to either Si-O^[59] or C-O stretching in alcohol, ether or hydroxyl groups.^{[60],[61]} The band at 1150 cm⁻¹ can also be associated with ether C-O symmetric and asymmetric stretching vibration (-C-O-C- ring)^[62]. This band could also be attributed to the anti symmetrical Si-OSi stretching mode as a result of existing alumina and silica containing minerals within the waste samples^[63]. The region 450-750 cm⁻¹ show two bands in the 480 and 485 cm⁻¹ which are associated with the inplane and out-of-plane aromatic ring deformation vibrations^[64]. Peaks at 598 and 680 cm⁻¹ are assigned to the out-of-plane C-H bending mode.

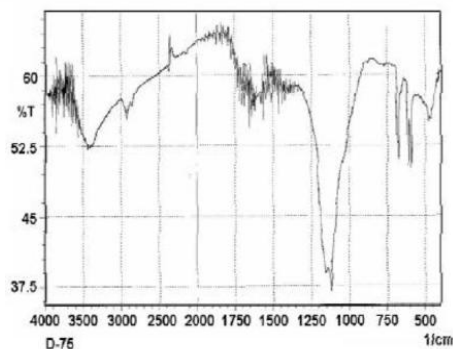


Figure.4.5: FT-IR spectrum for activated carbon from waste

4.8 XRD analysis:

X-ray diffractograms for both the activated waste and activated carbon are shown in Figures 3 and 4. The XRD spectra of the activated waste illustrated the presence of different aluminosilicate minerals. Zeolite X-Y was observed at $2\theta = 29.4$ with relative intensity of 158 cps, followed by faujasite detection at $2\theta = 26.5$. Other peaks were located at $2\theta = 32.9, 35.9$ and 39.4 for mullite, hematite and quartz, respectively. While the rest of the peaks for sodalite, analcime and sodium silicates re located at $2\theta = 43.1, 47.5$ and 48.5 ,

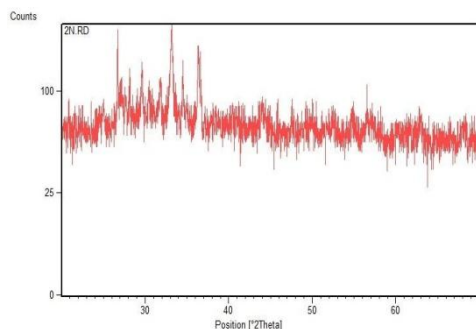


Figure.4.6: X-ray diffract gram for waste sample from waste

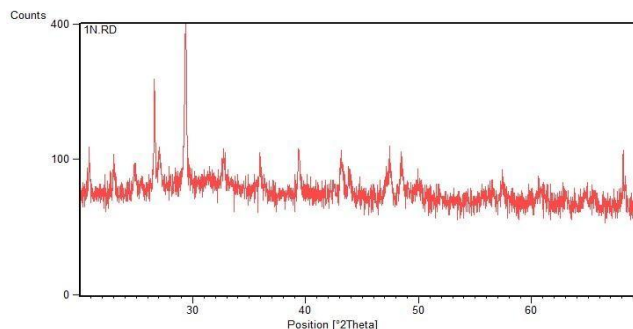


Figure 4.7: X-ray diffract gram for activated carbon

4.9 Scanning electron microscope analysis:

The sample of activated carbon produced out of the best operating conditions like 2.0M $ZnCl_2$ activating solution, impregnation time of 20 h, activation temperature of 600 C for 1 h, was analyzed in a scanning electron microscope. The surface physical morphology of activated carbon was observed by a scanning electron microscopy (SEM) (S-2150, Hitachi HighTechnologies Corp., Japan). SEM photograph shows that wide variety of pores is present in activated carbon along with fibrous structure. $ZnCl_2$ and NaOH impregnated carbon consists of more canals like structure than the untreated carbon. In cases of $ZnCl_2$ and NaOH impregnated activated carbon, surfaces are pitted and fragmented. Those imperfections are not seen in case of untreated waste.

V. CONCLUSIONS

The results of this study show that it is feasible to prepare activated carbons with relatively high surface areas and pore volumes from paper waste by direct chemical activation. An activation with $ZnCl_2$ produced activated carbons with better developed porosities than with KOH or KCl. The iodine value of the activated carbon product increased with concentration of $ZnCl_2$ solution (up to 2 N). As the impregnation time increased, the iodine value rose steeply, reaching a maximum value of 764.8mg/gm after 20 h. The iodine value also increased with activation temperature up to 600 C, beyond which it gradually decreased, presumably due to excessive carbonization. While prolonging the activation time, the iodine value of $ZnCl_2$ -activated carbon increased and then reached its maximum at 1 h. A longer activation time could induce negative effect on the carbon structure, and, thus, decrease the iodine value. In order to have a high surface area carbon and to minimize the energetic cost of the process, the following optimal conditions, 2.0M $ZnCl_2$ activating solution, impregnation time of 20 h, activation temperature of 600 C for 1 h were achieved. Under these conditions,

activated carbon with a relatively high specific surface area of 737.6m² /g and high iodine value of 764.8mg/ g was produced from paper waste by direct chemical activation.

The porosity of the product was comparable with that of commercially achieved carbon. The waste-based activated carbon had a mean pore diameter of 6.72 nm, and its total pore volume and micro pore volume were 0.19 and 0.15cm³ /g, respectively, indicating its micro porous and meso porous character.

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