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Synthesis and Consequence of Discrete Activating Agents on the Surface Functionality of Activated Carbons Derived from Abutilon Indicum Leaves

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ABSTRACT

This work is intended to examine the synthesis of activated carbons (AC) to review the impact of chemical activation by different activators on the surface functionality of activated carbons. The waste biomass and have no monetary value that is Abutilon Indicum leaves (AIL) was drawn into carbonized carbon (AIL300) through muffle furnace at 300^{o}C temperature. The carbon derived from AIL using three different chemical activators namely Zinc Chloride, Phosphoric acid and Nitric acid were explored at 300^{o}C activation temperature. The consequences of different chemical activating agents were recorded with the support of FTIR, percent yield and pH. Surface functionality of activated carbons gets enabled according to the activating agents and it affects the utilization of ACs for different purposes.

Keywords: - Abutilon Indicum leaves, Chemical activation, $ZnCl_2$, H_3PO_4, HNO_3

1. INTRODUCTION

Activated carbon (activated charcoal) is a highly porous carbon material processed to greatly increase its surface area, improving its adsorption and chemical reactivity. It is composed mainly of carbon atoms and can be produced from carbon-rich materials such as hardwood, softwood, lignite, and coal. Recently, growing interest in sustainable and low-impact resources has encouraged the use of carbon-rich waste materials for activated carbon production. These include industrial residues and agricultural by-products such as paper-mill sludge, bagasse fly ash, rice husks, date and peat stones, oil-palm waste, palm-kernel shells and fibers, coconut shells, periwinkle and snail shells, bamboo waste, and similar materials[1]. Activated carbon is generally produced through two stages: carbonization followed by activation. During carbonization, carbon-rich raw materials are heated in an inert atmosphere to form char and develop initial porosity. In the activation step, the char is further treated to enlarge and develop pores, greatly increasing porosity and adsorption capacity [2]. The thermal decomposition of biomass varies with the activating agent used. Phosphoric acid (H_3PO_4) functions as both an activator and catalyst, enhancing surface area and creating structural defects that act as anchoring sites for metal particles. It also promotes bond cleavage, cyclization, condensation, and crosslinking within the carbon structure [3]. Studies on palm-shell-based activated carbon for wastewater treatment show that chemical or physical modification can further increase pore development and surface area, improving adsorption performance[4]. Similarly, parameters such as dye concentration and carbonization time influence the yield and quality of zinc-chloride-activated carbon prepared from date stones [5]. The objective of this study is to produce activated carbon from waste Abutilon Indicum leaves using $ZnCl_2$, H_3PO_4, and HNO_3, and to evaluate how the functional groups of these activating agents and selected processing variables affect the properties and performance of the resulting ACs.

2. EXPERIMENTAL

Sample pre-treatment, Carbonization, and Activation

Abutilon Indicum leaf waste was collected from farms near Malkapur, Buldhana district, Maharashtra (India). The leaves were thoroughly washed to remove impurities and sun-dried for 5–7 days, then cut into small pieces. Moisture was removed by oven drying at 110 °C for 1 hour. The dried biomass was carbonized in a muffle furnace at 300 °C for 1 hour, cooled to room temperature, washed with double-distilled water, and oven-dried at 110 °C. The carbonized material was ground, sieved (100–200 mesh), and chemically activated following Girgis et al. (1999) with slight modifications. For activation, 25 g of carbonized sample was impregnated with aqueous zinc chloride, phosphoric acid, and nitric acid in a 1:5 ratio and kept for 12 hours. The mixture was then heated at 300 °C for 1 hour in a muffle furnace, cooled, washed with distilled water, and dried at 110 °C. The final activated carbon was sieved through a 150-µm mesh and stored in an airtight container[6].

Table: 1 List of carbonized and activated carbons of Abutilon Indicum leaves.

Sr. No.	Abutilon Indicum leaves sample	Sample Code
1	Carbonized at 300°C	AIL300
2	Activated at 300°C by using $ZnCl_2$	AIL300Zn
3	Activated at 300°C by using Phosphoric acid	AIL300P
4	Activated at 300°C by using Nitric acid	AIL300NA

2.1 Assessment of yield

Activated carbon yield was calculated by using given formula[7]

$$(\%)\text{Yield} = \frac{\text{Amount of AC after activation}}{\text{Amount of the raw material before activation}} \text{X } 100$$

2.2 Measurement of pH

One gram of sample was taken into a 250 ml beaker, then 100 ml of distilled water was added and swirled for fifteen minutes. The AC samples were kept unaltered, and a digital pH (Equiptronics EQ- 610) metre was used to find the pH[8, 9]

2.3 Surface Functional Group Analysis: The FTIR spectroscopy (Thermo Scientific iD3) was used to estimate the surface functional groups of activated carbons synthesized at varying temperatures. The FTIR spectra of all the samples were recorded in the range of 500 to 4000 cm⁻¹.

3. RESULT AND DISCUSSION

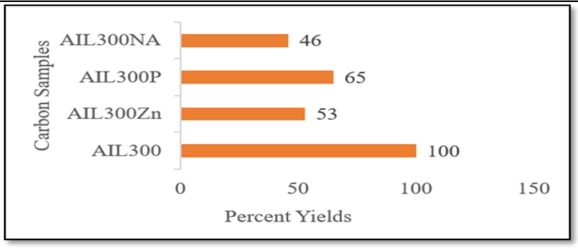

Figure 1: Percent Yields of different ACs at 300°C temperature.

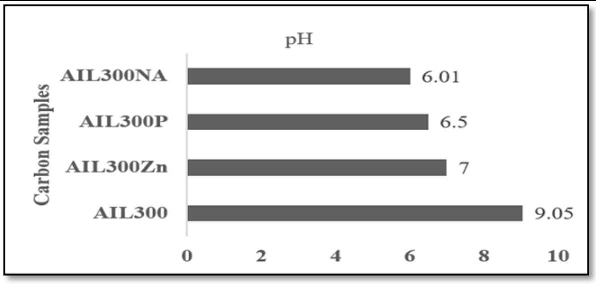

Figure 2: pH of Different Activated Carbon Samples.

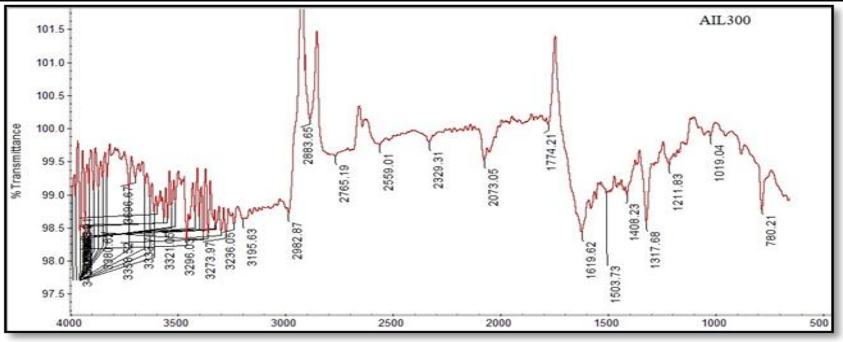

Figure 3: FTIR of AIL300.

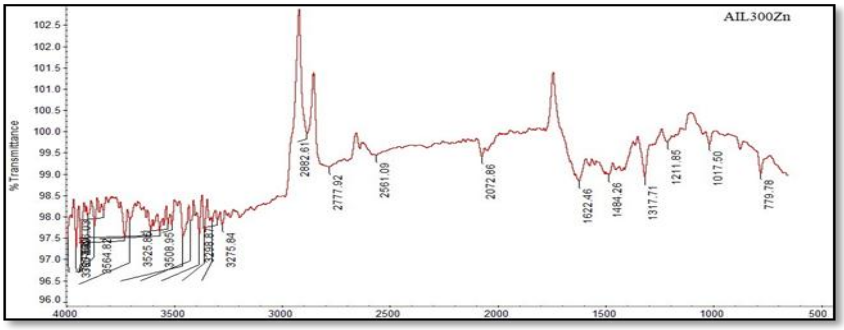

Figure 4: FTIR of AIL300Zn

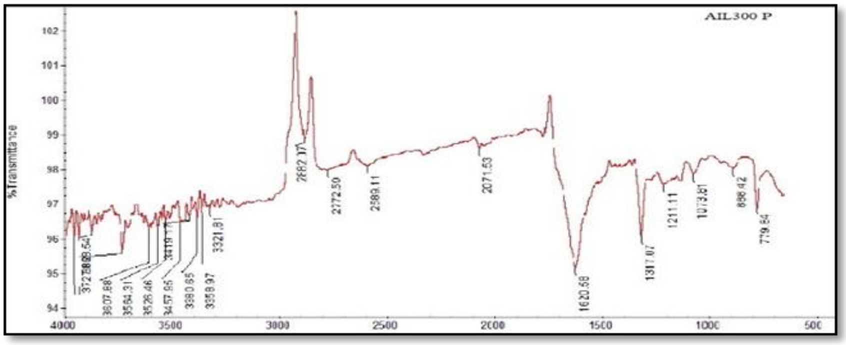

Figure 5: FTIR of AIL300P

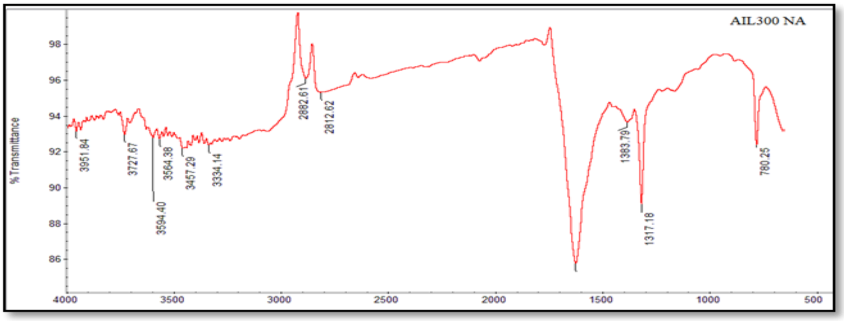

Figure 6: FTIR of AIL300NA.

3.1 Yield

The percent yields of the carbon samples prepared from Abutilon Indicum leaves at 300 °C are presented in Figure 1. The carbonized sample (AIL300) showed the highest yield of 100%, whereas the chemically activated samples exhibited comparatively lower yields: AIL300P (65%), AIL300Zn (53%), and AIL300NA (46%). The differences in biochemical composition, including cellulose, hemicellulose, and lignin content, as well as moisture and volatile matter, may be responsible for these variations in carbon yield [10]. The higher yield of AIL300 indicates that simple carbonization at 300 °C results in partial devolatilization[11] with minimum structural degradation of the biomass matrix. Since no activating agent was used, there was limited mass loss due to leaching or burn-off, and most of the solid char remained intact. However, this higher yield generally corresponds to a denser structure with fewer pores and lower adsorption efficiency. A noticeable reduction in yield was observed after chemical activation. This behaviour is typical because activating agents promote: dehydration and depolymerisation of lignocellulosic components, removal of volatile fractions, dissolution of unstable carbonaceous matter during washing[12]. Among the activated samples, AIL300P exhibited the highest yield (65%). Phosphoric acid promotes structural cross-linking and matrix stabilization, which restricts excessive burn-off and helps retain more solid carbon. This suggests that H_3PO_4 activation favours moderate pore development while maintaining good structural integrity. The yield of AIL300Zn (53%) was slightly lower, which may be attributed to stronger dehydration and aromatization reactions induced by $ZnCl_2$[13], resulting in greater mass loss during thermal treatment and subsequent washing. Despite reduced yield, $ZnCl_2$ activation is usually associated with enhanced micropore formation and higher surface area, which improves adsorption capacity. The lowest yield was obtained for AIL300NA (46%). Nitric acid behaves predominantly as an oxidizing agent, leading to partial surface oxidation and burn-off of thermally unstable fractions. The aggressive oxidation and washing steps likely contributed to the maximum material loss. Although yield is lower, nitric acid treatment introduces oxygen-containing functional groups that enhance surface acidity and may improve adsorption of cationic pollutants[14].

3.2 pH

The pH values of the Abutilon indicum leaf–derived carbon samples are presented in Figure 2. A considerable variation in surface acidity and alkalinity was observed depending on the type of activation treatment. The carbonized sample AIL300 exhibited the highest pH of 9.05, indicating a distinctly alkaline surface. In contrast, the chemically activated samples showed comparatively lower pH values: AIL300Zn (7.0), AIL300P (6.5) and AIL300NA (6.01). The alkaline character of AIL300 can be attributed to the presence of basic mineral residues and thermally stable inorganic components retained during carbonization at 300 °C[15]. In the absence of chemical treatment, these ash constituents are not leached out, which results in a higher pH[16]. However, such carbons generally possess limited surface functionality, and their alkalinity mainly reflects residual inorganic content rather than chemical modification of the carbon framework. A gradual decrease in pH was observed after activation, which confirms that chemical treatment plays an important role in modifying surface chemistry. The pH of AIL300Zn (7.0) is neutral, suggesting partial removal of alkaline minerals along with the development of oxygen-based functional groups during $ZnCl_2$ activation and subsequent washing. This balance between inorganic removal and structural reorganization leads to a relatively neutral surface, which is favourable for adsorption of both acidic and basic solutes[17]. The phosphoric acid–activated sample AIL300P (pH 6.5) exhibited a mildly acidic character. During H_3PO_4 activation, phosphate species and oxygen-containing surface groups may be introduced onto the carbon matrix, which increases surface acidity. The presence of such functionalities enhances affinity toward basic and polar contaminants in aqueous systems[18].

3.3 FTIR Analysis

FTIR spectroscopy was used to identify the surface functional groups on activated carbons derived from Abutilon Indicum leaves. The spectra of AIL300, AIL300Zn, AIL300P, and AIL300NA show clear variations in band intensity and distribution, indicating that the activating agent significantly influences surface chemistry. AIL300 exhibits a broad band at 3300–3400 cm^{-1} due to –OH stretching from moisture and residual hydroxyl groups[19], with weak aliphatic C–H bands at 2850–2920 cm^{-1} indicating remaining organic structures[20]. Aromatic C=C bands at 1600–1650 cm^{-1} confirm initial carbon skeleton formation, while bands at 1000–1200 cm^{-1} (C–O stretching) show that carbonization at 300 °C retains oxygenated functional groups. In AIL300Zn, the reduction of aliphatic C–H bands indicates stronger dehydration and structural rearrangement during $ZnCl_2$ activation. A more intense aromatic C=C band (1580–1620 cm^{-1}) reflects increased aromatization, while bands at 1100–1150 cm^{-1} suggest C–O/C–O–C linkages formed through cross-linking [21]. Weaker hydroxyl peaks indicate removal of unstable oxygen groups, showing that $ZnCl_2$ promotes a more condensed and microporous carbon structure with limited oxygen functionalities. AIL300P displays broader oxygen-containing bands, with the 3400 cm^{-1} peak attributed to –OH and phosphate-related groups. Peaks at 1200–1250 and 1000–1100 cm^{-1} correspond to P–O–C and P=O vibrations, confirming phosphate incorporation[22]. The aromatic C=C band remains visible at 1600–1650 cm^{-1}, indicating coexistence of aromatic structures and phosphate cross-linking. These acidic phosphate groups enhance surface polarity and potential ion-exchange behaviour. AIL300NA shows the highest concentration of oxygenated groups, with a broad –OH band at 3300–3400 cm^{-1} and a strong C=O peak at 1700–1720 cm^{-1} indicating significant surface oxidation [23]. Bands at 1380–1450 cm^{-1} suggest nitrate or $–NO_2$ functionalities, while absorptions at 1000–1200 cm^{-1} correspond to phenolic and ester C–O stretching. These results confirm that nitric acid on the Activated carbon was successfully increasing the physical properties of activated carbon involving surface area, pore size distribution and pore volume[24].

4. CONCLUSIONS

Activated carbons prepared from Abutilon indicum leaves showed that both the activation method and the activating agent strongly affect their physicochemical properties. Carbonization at 300 °C without chemicals (AIL300) produced the highest yield and an alkaline surface, but the material largely retained char-like characteristics with limited surface functionality. Chemical activation reduced yield but markedly altered surface chemistry and functional group distribution. $ZnCl_2$ activation (AIL300Zn) resulted in a lower yield and near-neutral pH, with greater aromatization and stable oxygen groups, indicating a more condensed carbon matrix suitable for microporous adsorption. Phosphoric acid activation (AIL300P) gave a relatively higher yield among activated samples and produced mildly acidic carbons containing phosphate-linked groups, suggesting better structural stability and suitability for adsorption of basic and polar contaminants through ion-exchange and surface interactions. Nitric acid activation (AIL300NA) produced the lowest yield and the most acidic surface, as evidenced by FTIR bands of carboxylic, lactonic, and other oxidized groups. Although associated with higher material loss, it yielded a highly functionalized and hydrophilic surface favorable for adsorption of cationic species and metal ions. Overall, the results indicate that Abutilon Indicum leaves are a promising low-cost precursor for activated carbon production, and that the choice of activating agent effectively tailors yield, surface acidity/alkalinity, and chemical functionality for specific adsorption and environmental remediation applications.

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