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COMPREHENSIVE PHYSICOCHEMICAL CHARACTERIZATION OF ACTIVATED CARBON MATERIALS FOR MEDICAL ENTEROSORBENT APPLICATIONS

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ABSTRACT

Activated carbon is extensively utilized in pharmaceutical practice as an enterosorbent due to its high adsorption efficiency and chemical inertness. This study aimed to comparatively assess several industrial activated carbon samples to evaluate their suitability for therapeutic enterosorption. Prior to characterization, all samples were subjected to standard laboratory purification protocols. Critical physicochemical properties, including ash content, bulk density, and pH of aqueous extracts, were measured following pharmacopeial and standardized procedures. The analysis revealed that only the AU-K sample met the regulatory criteria for medical-grade activated carbon, particularly in terms of ash content and pH. Other samples demonstrated elevated levels of mineral impurities, which could compromise both sorption performance and biological safety. These results underscore the necessity of comprehensive physicochemical evaluation when selecting activated carbon for pharmaceutical applications.

Introduction. Activated carbon is widely recognized as one of the most frequently employed sorbent materials in both pharmaceutical and medical practice. Its broad applicability stems from several intrinsic physicochemical properties, including a highly developed porous network, an extensive specific surface area, and notable chemical stability. These characteristics collectively enable activated carbon to efficiently adsorb a wide range of molecules and particulates. In clinical and therapeutic contexts, activated carbon is predominantly utilized as an enterosorbent. It functions by selectively binding and sequestering various endogenous and exogenous substances, including metabolic by-products, dietary or environmental toxins, and pathogenic microorganisms, within the gastrointestinal tract. By immobilizing these potentially harmful agents, activated carbon

effectively reduces their absorption into the systemic circulation, thereby mitigating toxic effects and supporting overall metabolic and immunological homeostasis [1,2].

The functional efficiency and overall performance of activated carbon in pharmaceutical applications are largely determined by a set of critical physicochemical properties. Among these, three parameters are particularly significant: ash content, surface acid–base characteristics (commonly represented by pH), and bulk density. Ash content serves as an important indicator of the presence of inorganic residues or mineral impurities within the carbon matrix. Elevated levels of ash not only occupy active adsorption sites but also reduce the material's overall sorption efficiency, potentially limiting its ability to effectively capture and immobilize target molecules. Moreover, a high ash fraction may pose safety concerns, as inorganic contaminants could negatively influence the quality and biological compatibility of pharmaceutical preparations. In clinical and therapeutic settings, activated carbon is widely employed as a highly effective enterosorbent, playing a crucial role in the management of gastrointestinal and systemic toxicities. Its mechanism of action involves the selective adsorption and immobilization of a diverse array of both endogenous and exogenous compounds within the digestive tract. These substances include metabolic by-products generated through normal physiological processes, as well as dietary, environmental, or pharmacological toxins that may pose health risks. Additionally, activated carbon has the capacity to bind pathogenic microorganisms present in the gastrointestinal milieu, thereby limiting their proliferation and subsequent systemic effects. By sequestering such potentially harmful agents, activated carbon effectively prevents their absorption into the bloodstream, reducing systemic exposure and mitigating the risk of toxic or adverse effects. This targeted adsorption not only serves a detoxifying function but also contributes to the maintenance of metabolic balance and immunological homeostasis, supporting overall physiological stability. The multifaceted action of activated carbon underscores its importance in therapeutic protocols designed to manage poisoning, reduce gastrointestinal pathogen load, and enhance patient safety, making it an indispensable tool in both preventive and interventional clinical practice. [3]. Pharmacopoeial guidelines emphasize the importance of this parameter, stipulating that medical-grade activated carbon should contain no more than 4% ash [4], thereby ensuring both its efficacy and suitability for clinical use. In addition to ash content, the acid–base properties of the carbon surface, typically expressed through pH measurements, play a crucial role in determining the interaction of activated carbon with various solutes. Deviations from the optimal pH range can influence not only the adsorption kinetics and selectivity but also the stability of the material in aqueous environments. Bulk density, another key characteristic, affects both the handling and processing of activated carbon, as well as its packing and flow properties during formulation. Together, these physicochemical attributes form an interdependent set of parameters that govern the sorptive behavior, operational efficiency, and safety profile of activated carbon in pharmaceutical contexts. Consequently, a comprehensive evaluation of ash content, surface pH, and bulk density is indispensable for ensuring that selected activated carbon samples meet the stringent standards required for therapeutic and clinical applications. Surface acid–base properties, commonly assessed through pH

measurement, constitute another crucial factor determining the adsorption behavior of activated carbon. The pH of the material influences the ionization state of both the adsorbent and adsorbate, thereby affecting interaction strength, adsorption kinetics, and selectivity. Deviations from an optimal pH range can compromise adsorption efficiency, while also potentially altering the chemical stability of the material under aqueous conditions. Bulk density, on the other hand, impacts the handling, packing, and flow properties of activated carbon, which are essential for uniform dosing, reproducible sorption performance, and ease of incorporation into pharmaceutical formulations.

Taken together, these physicochemical characteristics—ash content, surface pH, and bulk density—form an interdependent set of factors that collectively define the functional efficiency, safety profile, and suitability of activated carbon for medical and pharmaceutical use. Therefore, a comprehensive and systematic evaluation of these parameters is essential when selecting activated carbon for enterosorption and other therapeutic applications. Such assessment ensures that only materials meeting stringent quality criteria are employed, ultimately contributing to the efficacy, reliability, and safety of pharmaceutical products.

Materials and Methods.

For the present study, four commercially available activated carbon samples—DAU, KAU, AAU-560, and AU-K—were selected to evaluate their physicochemical properties and suitability for pharmaceutical applications. These samples were chosen based on differences in their raw material origin, methods of activation, and intended industrial purposes, providing a representative comparison of commercially utilized activated carbons. For laboratory-scale preparation, 150 cm^3 of each wet activated carbon sample was placed into a 1000 mL flat-bottomed flask and subjected to repeated boiling cycles (two to three times) in a fivefold excess of distilled water. This rigorous washing procedure was designed to remove soluble mineral and organic impurities that could interfere with subsequent analyses and compromise the accuracy of physicochemical measurements. Following thorough washing, the samples were transferred to a drying oven and maintained at 105 ± 5 °C until a constant mass was achieved, ensuring complete removal of moisture while preventing thermal degradation of the carbon structure. After drying, the activated carbon samples were cooled in a desiccator to maintain low humidity and were subsequently stored in airtight containers to prevent moisture uptake and preserve their physicochemical integrity. This systematic pre-treatment ensured that all samples were in a consistent, stable condition prior to analytical characterization, thereby enabling a reliable comparison of their ash content, pH, bulk density, and adsorption properties. The methodology employed here provides a robust framework for the preparation of activated carbon samples for both research and pharmaceutical quality assessment purposes [5].

The ash content of the activated carbon samples was determined using a gravimetric method. Approximately 1.0 g of each dried and finely ground sample was accurately weighed and transferred into a pre-calcined porcelain crucible. The calcination process was carried out in two distinct stages to ensure complete removal of non-carbonaceous material. Initially, the sample was heated at a temperature not exceeding 300 °C to

volatilize moisture and other easily oxidizable components. This was followed by high-temperature calcination at 825–850 °C, maintained until the sample attained a constant mass, indicating complete combustion of organic matter. The ash content was subsequently calculated as a percentage of the original sample mass, providing a quantitative measure of the inorganic residue present in each activated carbon sample. This method allows for precise assessment of mineral impurities, which is critical for evaluating the quality and suitability of activated carbon for pharmaceutical applications. Bulk density of the activated carbon samples was determined by measuring the mass of a precisely known volume of the material without applying any compaction, and the results were expressed in grams per cubic decimeter (g/dm^3) [6,7]. The pH of aqueous extracts was assessed potentiometrically, following standard pharmacopoeial procedures. To prepare the extracts, 10 g of granulated activated carbon was combined with 100 mL of distilled water, boiled for three minutes under a reflux condenser, and subsequently filtered. The resulting filtrate was allowed to cool to room temperature before potentiometric pH measurement. This approach ensures accurate determination of the surface acid–base properties of the activated carbon, which are critical for evaluating its adsorption behavior and suitability for pharmaceutical applications [4].

Results and Discussion. The ash content results are presented in Table 1.

Table 1

Ash content of the investigated samples

Sample	Sample mass, g	Ash mass, g	Ash content, %
DAU	1,1436	0,14295	12,50
KAU	1,0199	0,1080	10,59
AAU-560	1,0111	0,5434	53,74
AU-K	1,0002	0,0174	**1,74**

Among the investigated samples, only the AU-K activated carbon met the regulatory requirement for ash content, maintaining a level at or below 4%. In contrast, the DAU, KAU, and particularly the AAU-560 samples exhibited substantially higher ash contents, reflecting a notable presence of mineral impurities. Such elevated levels of inorganic residues can negatively impact the adsorption capacity of the carbon and may compromise its safety and suitability for pharmaceutical applications [8]. These findings underscore the importance of stringent quality assessment, as ash content serves as a critical determinant of both the functional performance and biological compatibility of activated carbon in therapeutic and medical contexts.

Bulk density results are summarized in Table 2.

Table 2

Bulk density of the samples

Sample	Volume, cm^3	Mass, g	Bulk density, g/dm^3
DAU	10	8,35	835
KAU	–	7,415	741,5
AAU-560	–	2,8	280

AU-K	–	5,4618	546,18

The low bulk density of AAU-560 indicates a loose structure; however, in combination with extremely high ash content, this does not lead to improved sorption performance. The AU-K sample demonstrates an optimal balance between bulk density and carbon matrix purity [9].

The pH values of aqueous extracts are presented in Table 3.

Table 3

pH values of aqueous extracts

Sample	**pH**
ДАУ	5,6
КАУ	6,83
ААУ-560	8,35
АУ-К	6,77

Pharmacopoeial guidelines stipulate that the pH of activated carbon intended for medical applications should fall within the range of 6.0 to 8.0. Among the samples evaluated, both KAU and AU-K were found to comply with this requirement, exhibiting pH values within the acceptable limits. In contrast, the DAU sample demonstrated an acidic character, while AAU-560 displayed an alkaline reaction that exceeded the permissible range. Deviations from the specified pH range can influence the surface acid–base properties of activated carbon, potentially affecting its adsorption behavior, stability in aqueous media, and overall suitability for therapeutic use [4,10].

Conclusions. The findings of the present study indicate that the overall quality and performance of activated carbon are highly dependent on both the production technology employed and the extent of purification achieved. Among the four samples examined, only

AU-K fully satisfied the regulatory criteria, exhibiting an ash content within the permissible limit, a pH value in the specified range, and an acceptable bulk density suitable for pharmaceutical applications. In contrast, the DAU, KAU, and AAU-560 samples displayed elevated levels of mineral impurities, which could compromise their adsorption efficiency and limit their applicability for medical enterosorption. These results align with recent reports in the literature, underscoring the critical influence of raw material selection, activation methods, and post-production treatment on the physicochemical properties of activated carbon. Collectively, the data highlight the necessity of a thorough and systematic evaluation of ash content, pH, and bulk density when selecting activated carbon for therapeutic and medical purposes, ensuring both efficacy and safety in clinical applications.

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