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Enhanced Rainwater Purification using Cold Plasma-Activated Hyacinth Adsorbent for Pollutant Reduction

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ABSTRACT

This purpose of research for designing a filtration system utilizing hyacinth-based adsorbents to purify rainwater. Hyacinth which an agricultural waste rich in cellulose, possesses natural adsorptive properties. This explores of plasma cold-activated hyacinth adsorbents for rainwater purification, addressing a significant gap in sustainable water treated technologies. Unlike conventional adsorbents, the activation process using cold plasma enhances the adsorbent's surface properties, increasing its efficacy in removing pollutants. A comparative analysis with traditional purification methods demonstrates the superior performance of plasma-activated hyacinth in terms of adsorption capacity and pollutant reduction efficiency. By integrating cold plasma technology with a low-cost, eco-friendly adsorbent, this approach offers a novel solution to improving rainwater quality while promoting environmental sustainability. The study examined variations in carbonization temperatures (600 °C) and evaluated the characteristics of cold plasma-treated and untreated hyacinth adsorbents. Characterization techniques included Scanning Electron Microscopy (SEM) for surface morphology, emission intensity analysis via Optical Electron Spectroscopy to detect plasma-generated species, and Fourier Transform Infrared Spectroscopy (FTIR) to identify functional groups. Results showed that the plasma cold produced Reactive Nitrogen Species (RNS) at wavelengths 324.768–445.289 nm, Reactive Argon Species (R-Ar-S) at 698.223–778.398 nm, and Reactive Oxygen Species (ROS) at 780.341–830.867 nm. SEM analysis revealed that the surface texture of untreated hyacinth adsorbents was smooth, while plasma-treated adsorbents exhibited a rougher surface, enhancing adsorptive efficiency. FTIR analysis identified functional groups such as C=C, C-C, C-N, C=O, and C-O within the range of 700–1750 nm. Rainwater purification efficiency improved significantly with plasma-treated adsorbents, as indicated by reductions in COD (16.22 mg/L), BOD (7.49 mg/L), and TDS (120.22 mg/L), compared to untreated adsorbents, which showed COD of

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32.44 mg/L, BOD of 20.26 mg/L, and TDS of 180.46 mg/L. These findings demonstrate the effectiveness of plasma cold-activated hyacinth adsorbents in enhancing rainwater quality.

1. Introduction

Rainwater harvesting systems are increasingly becoming an integral part of sustainable rainwater management efforts [1]. The major problem of insufficient water supply and inadequate water treated is a major challenge in developing countries. Therefore, we need to look for alternative approaches that consider the financial and technical limitations that poor countries have, especially in semi-urban or rural areas [2]. Rainwater harvesting is considered a highly relevant alternative water source, especially in urban and developing countries. Rainwater harvesting has long been advocated as a useful technology in regions of the world that experience dry seasons. On the other hand, the thing that need to be considered is that the quality of collected rainwater depends on various factors, including the type of roofing material and environmental conditions such as local climate and levels of atmospheric pollution [3]. Pollution from roofs can be classified into external and internal pollution sources. External sources include air pollutants and organic substances originating from human activities, leaves, and bird droppings [4]. The main pathogenic bacteria that can be found on rooftops come from bird and mammal droppings that can access the rooftop. The source of internal pollution comes from the roof material itself. Rainfall or precipitation is the main process in which gases and aerosols from the atmosphere combine and fall to the Earth's surface. This process plays a key role in rainwater chemistry by cleaning the air in clouds and below clouds. As a result, rainwater contains various types of chemical compounds such as ammonia, sodium, potassium, calcium, magnesium, hydrogen, sulfate, chloride, nitrate, bicarbonate, and carbonate ions [5]. The concentration of hydrogen ions is a very important parameter for assessing the acidity level of rain, which is often known as acid rain. Currently, there are several methods in use to eliminate dyes and metals from water. Some of these processes include membrane filtration, adsorption, chemical precipitation, electrolysis, ion exchange, electrocoagulation, cavitation, and ultra-sonication [6].

The adsorption method tends to be preferred over other methods because it has several advantages. First, this method is easy to operate, so it does not require special skills to use. In addition, the adsorption process has high efficiency in removing dyes and metals from water, even at low concentrations [7]. This makes it suitable for treating water with varying levels of pollution. Apart from its efficiency, the adsorption method is also considered safer because it does not produce by-products that are harmful to the environment or human health [7]. Economic aspects are also an important consideration in selecting water treated methods. For this reason, the adsorbent material used must meet several requirements. First, the material must be available in abundance in nature, so that it can be accessed easily. Apart from that, the ideal adsorbent material is one that has no or low economic value, so that production and use costs can be reduced. In addition, adsorbent materials must be easily prepared from by-products or industrial or agricultural waste, thereby minimizing environmental impacts and ensuring the continued continuity of water treated processes [7]. Taking all these factors into consideration, the adsorption method becomes a viable option to overcome the problem of removing dyes and metals from water, especially in the context of natural resource availability and economic aspects.

This research has the main objective of developing eco-friendly and inexpensive adsorbents to eliminate dangerous heavy metals from rainwater. The method involves studies to measure the absorption ability of adsorbents made from hyacinth [8]. The selection of water hyacinth adsorbent as an alternative in the rainwater purification process has a number of advantages compared to conventional adsorbents, including: (1) Water hyacinth is an invasive plant that is often considered environmental waste. By utilizing water hyacinth as an adsorbent, we not only reduce its negative impact on the ecosystem, but also provide abundant and cheap raw materials [9]. (2) Unlike conventional adsorbents that often require hazardous chemicals in their production process, water hyacinth can be processed into adsorbents simply and with minimal environmental impact, especially if using technology such as plasma activation [10]. (3) Water hyacinth has a high cellulose content and a pore structure that supports good adsorption capacity. With an activation process such as using cold plasma, its adsorption capacity for contaminants such as heavy metals and organic compounds can be significantly increased [11]. (4) Water hyacinth-based adsorbents have much lower production costs compared to commercial adsorbents, such as activated carbon [12]. This makes it a more economical option, especially for applications at community scale or in remote areas.(5)Utilizing water hyacinth to produce adsorbents can open up opportunities for local communities to process plant waste into value-added products, while helping to address environmental issues.(6)Activation processes, such as with cold plasma, allow for the modification of the surface properties of water hyacinth adsorbents to suit specific needs, such as the purification of water containing certain contaminants, which is difficult to achieve with conventional adsorbents [13]. The adsorbent manufacturing process involves the use cold plasma to activated. Plasma technology is used to enlarge or create pores on the surface of the adsorbent, increasing the specific surface area. This allows the adsorbent to bind more pollutant molecules, thereby increasing the adsorption capacity. Plasma produces reactive species (such as •OH, •O, and NOx) that interact with the surface of the adsorbent. This process increases the surface energy of the adsorbent, making it more reactive to target molecules such as heavy metals, dyes, or organic compounds. Plasma is able to add or modify functional groups (such as –COOH, –OH, or –C=O) on the surface of the adsorbent. These groups increase the affinity of the adsorbent for specific pollutants, thereby increasing its selectivity. Plasma technology allows for the modification of the surface of the adsorbent in a short time and can be applied to a variety of natural materials, such as biochar, sawdust, and biomass waste. To assess the adsorbent, scanning electron microscopy (SEM) is employed for characterization [14]. Furthermore, this research aims to optimize these parameters so that the adsorption to assist in the removal COD, BOD, TDS in rainwater can achieve the best results. Thus, this research offers a better alternative in rainwater treated that is more environmentally friendly and economical [15]. It is hoped that this effort can be an effective solution in overcoming the problem of pollution in rainwater.

Low-cost adsorbents are a promising alternative due to their abundant availability, low cost, and high efficiency in the adsorption process. Algae have been shown to be effective adsorbents due to their large pore structure and high adsorption capacity for organic pollutants and heavy metals. For example, studies have shown that dried algae can efficiently remove metals such as Pb, Cd, and Zn from aqueous solutions through ionic interactions and surface complexation [16]. In addition, chemically or thermally modified algae can enhance their adsorption capacity for dyes and other organic compounds [17]. Sugarcane bagasse, which is an agro-industrial waste, has also been widely used as a natural adsorbent. Sugarcane bagasse has a high cellulose content, which can be utilized to remove pollutants through physical and chemical mechanisms. Studies have shown that thermal and chemical activation of sugarcane bagasse increases the adsorption capacity of dyes such as methylene blue and heavy metals such as Cr and As [18]. In addition to algae and sugarcane bagasse, other low-cost materials such as biochar, sawdust, and volcanic ash have also been studied as adsorbents. Biochar produced from biomass has shown high efficiency in adsorbing heavy metals and dyes due to its large surface area and the presence of active functional groups [19]. Wood dust and other similar materials are frequently used in water treated due to their abundant availability and modifiable surface properties [20]. Recent studies have also revealed that nanomaterials such as graphene oxide and nanocomposites can be integrated with low-cost adsorbents to enhance pollutant removal efficiency. This combination offers great potential for optimizing sustainable water treated systems [21]. This approach is not only environmentally friendly but also provides a sustainable solution to utilize organic waste and low-cost materials as adsorbents, making it relevant for water management in areas facing resource constraints.

2. Methodology

2.1 Materials

The materials used in this study were rainwater with pH=5, hyacinth, Sodium Hydroxide Merck SAS 1310-73-2, Hydrochloric acid Merck 1.00731.2500, Aquades.

2.2 Instrumentation

The cold plasma that will be used in this research that utilizes a High Voltage Power Supply (HVPS). The HVPS is connected to an electrode in the form of a stainless steel rod with a thickness of 0.15 cm surrounded by a glass tube with an outer diameter of 0.5 cm and an inner diameter of 0.4 cm. Meanwhile, the electrode at the bottom is an aluminum tape connected to the ground. The distance between the electrodes is 8 cm and the ground electrode has a distance of 0.3 cm. The voltage on the power supply ranges from 0-20 kV. The argon gas used is flowed through a glass tube at a flow rate of 3 L/minute. The voltage frequency is 5.5 kV and 20 kHz. Current-voltage characteristics were measured using a Tektronik TDS 2002 oscilloscope connected to the probe. The emission intensity was measured using optical emission spectroscopy (OES). Experimental Design in Figure 1.

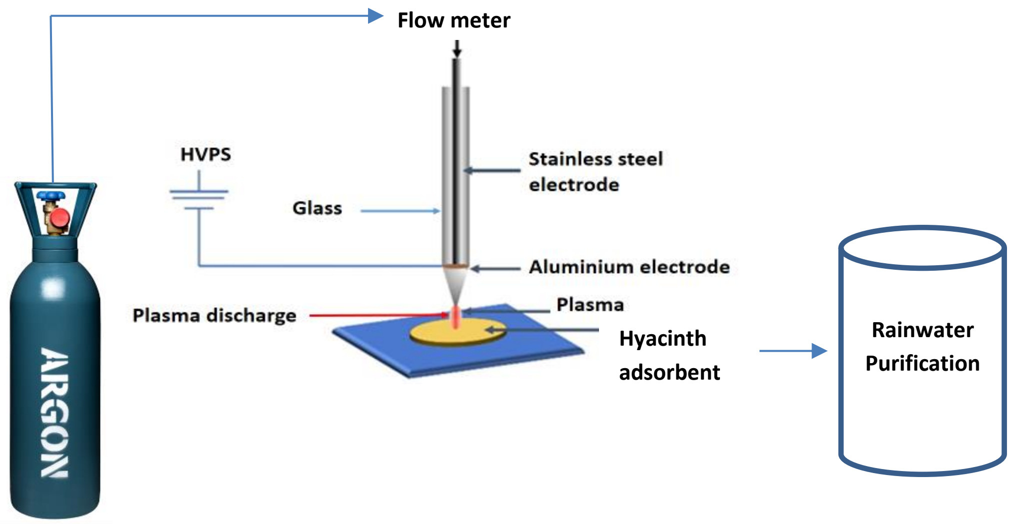


Fig. 1. Experimental setup

2.3 Procedure

2.3.1 Synthesis of adsorbent

In this research, the steps for preparing hyacinth for use as an adsorbent in water treated can be described as follows: First, the hyacin this collected and undergoes several washing stages using distilled water. This is done to remove unwanted contaminants and impurities from the hyacinyh. After the washing process, the hyacinth was dried in an oven for a period of 24 hours at 60°C. The goal is to reduce moisture in the hyacinth. Then, the dried hyacinthis crushed and ground into a fine powder so that it has a suitable texture for the adsorption process. The hyacinth powder is then filtered through a 40 mesh (450 µm) screen to ensure the particle size is as required. Then, the hyacinthis impregnated with hydrochloric acid (HCl) at ratios, such as hyacinth/HCl = 1:1.5. This process involves adding hydrochloric acid to stirred distilled water at 30°C. Next, the hyacinthis introduced into the mixture and stirred for a duration of 12 hours. Following the impregnation process, the mixture is filtered to separate the hyacinth from the hydrochloric acid solution. The separated hyacinthis then dried for a duration of 4 hours at the temperature of 60°C. Then, the hyacinth samples underwent a carbonization process by heating at 600°C [22].

2.3.2 Cold plasma treated

The sample was placed on a printing device with a square area of 1.0 x 1.0 cm and placed at a distance of 10 mm from the nozzle. Plasma treated was carried out for 1 minute by manually directing the cold plasma at 5 points on the sample. Plasma is shot into the center area for 20 seconds, then directed to the top, left, bottom and right center of the sample for 10 seconds each [23].

2.3.3 Surface analysis

A scanning electron microscope (SEM) was employed to analyze the surface morphology of the hyacint adsorbent samples. The surface of the hyacinth adsorbent with and without plasma cold treated was also compared. All SEM images were captured at a magnification of 10000x and a voltage of 20 kV. In the images, there is a scale bar with a maximum length of 20 µm, and the image angle is approximately 45° from the normal under vacuum conditions. Surface characteristics before and after plasma treated were compared using Fourier Transform Infrared Spectroscopy (FTIR; IRPrestige-21 Shimadzu) [24].

2.3.4 COD, BOD and TDS test

The experiments aimed to assess the effectiveness of hyacint has an adsorbent in removing various water quality parameters, including COD (Chemical Oxygen Demand), BOD (Biochemical Oxygen Demand), TDS (Total Dissolved Solids). These experiments were conducted in a batch reactor with a capacity of 250 mL, using 500 mg of adsorbent. To prepare the solution, the pH of the dye solution was adjusted as required by adding 0.1 N HCl or 0.1 N NaOH solution. The bagasse adsorbent, which has been accurately measured, is then added to the rainwater. Once added, the mixture is immediately stirred for 5 minutes with 150 rpm. At specific time intervals, samples were extracted from the batch reactor and subsequently centrifuged for 5 minutes at 400 rpm to separate the adsorbent particles from the solution. By carrying out this series of experiments, research can evaluate the ability of hyacinth adsorbents to remove the various water quality parameters that have been mentioned [25].

3. Results and Discussion

3.1 The Effect of Voltage and Argon Flowrate

This research employs a plasma jet powered by a High Voltage Power Supply (HVPS) with adjustable voltage up to 20 kV and a frequency of 20 kHz to optimize the plasma environment for activating adsorbents. The use of argon gas at a flow rate of 3 L/min in the glass tube ensures a stable plasma discharge, who emphasized the role of inert gases in generating reactive species for surface modification. Argon flow rate of 3 L/min is the optimum flow rate that provides stable conditions for plasma formation. Too low gas flow can cause plasma to become unstable, while too high flow can prevent plasma formation evenly around the adsorbent surface. Argon as an inert gas helps to maintain the plasma in a highly excited state without reacting directly with the adsorbent surface, allowing more effective interaction between plasma species and adsorbent. Argon flow at 3 L/min ensures efficient transport of reactive species (such as •OH, •O, and NOx) generated in the plasma to the adsorbent surface. If the flow rate is too low, the distribution of reactive species is uneven, reducing the effectiveness of adsorbent surface modification. Conversely, too high a flow rate can cause reactive species to be dispersed before reaching the adsorbent surface. Argon flow at a rate of 3 L/min supports sufficient etching process on the adsorbent surface, creating or enlarging pores, which increases the surface area and adsorption capacity. The appropriate flow rate ensures that the plasma energy is used effectively to modify the surface without causing degradation of the adsorbent material. The electrode configuration, with a stainless steel rod and aluminum ground electrode, mirrors the principles discussed in their work, where electrode spacing and material influence the uniformity and energy of the plasma discharge [26].

Additionally, the inclusion of current-voltage measurements using an oscilloscope providing critical insights into the electrical characteristics of the plasma and its impact on adsorbent surface properties. This alignment underlines the applicability of the described setup for achieving effective adsorbent surface modifications, consistent with the advanced adsorption performance reported in the referenced study. Increasing the voltage can introduce or change functional groups on the surface of the adsorbent, such as the addition of hydroxyl or carboxyl groups. These changes increase the affinity of the adsorbent for certain pollutants, increasing its adsorption capacity. Higher voltage can cause etching or new pore formation on the adsorbent surface, increasing the specific surface area and adsorption capacity. The voltage used is in the range of 0-20 kV and the importance of optimizing the HVPS voltage to achieve the desired surface modification on the natural adsorbent. This study was conducted at the optimum voltage limit of 5.5 kV where increasing the voltage provides maximum benefits; exceeding this limit may cause material degradation or other negative effects [27].

3.2 Emission Intensity of Cold Plasma

The high voltage in HVPS increases the energy of electrons in the plasma, which contributes to the formation of reactive species such as free radicals and ions. These species interact with the adsorbent surface, changing its chemical and physical structure. The formation of reactive species in plasma is usually caused by the mechanism of action of the plasma, the gas environment dispersed with the plasma, and the nature of the target interacting with it [18]. Plasma sources operate in an open environment, making selective production difficult. Most of the reactive species in plasma are formed simultaneously during discharge; therefore, it is difficult to determine the impact of each reactive species. Some reactive species can be useful according to their intended use, while others can be detrimental [28]. Comprehensive knowledge of selective production is necessary to exploit the full potential of plasma applications. Tailoring ROS and RNS production are critical to the success and application of targeted plasma sources.

Based on Figure 2, emission intensity of plasma jet produces Reactive Nitrogen Species (RNS) at λ = 324.768 nm until 445.289 nm, Reactive Argon Species (R-Ar-S) at λ = 698.223 nm until λ = 778.398 nm and Reactive Oxygen Species (ROS) at λ = 780.341 nm until λ = 830.867 nm. The emitted plasma produces various types of reactive oxygen species (ROS) and reactive nitrogen species (RNS) simultaneously, making frequency production difficult. In this study, an attempt was made to overcome this problem by adjusting the length of the downstream plasma jet to regulate the production of reactive species in an AC-driven argon of cold plasma. Jets with short downstream lengths are dominated by RNS, while jets with longer downstream lengths are dominated by ROS. High energy collisions between energetic electrons and the surrounding air are responsible for the formation of RNS in argon plasma. Short plasma jets have a higher electron temperature in the waste plasma, allowing better excitation and ionization of N_2 molecules. In contrast, in longer jets, electrons transfer most of their energy to neutrals and moisture, before finally diffusing into the surrounding air.

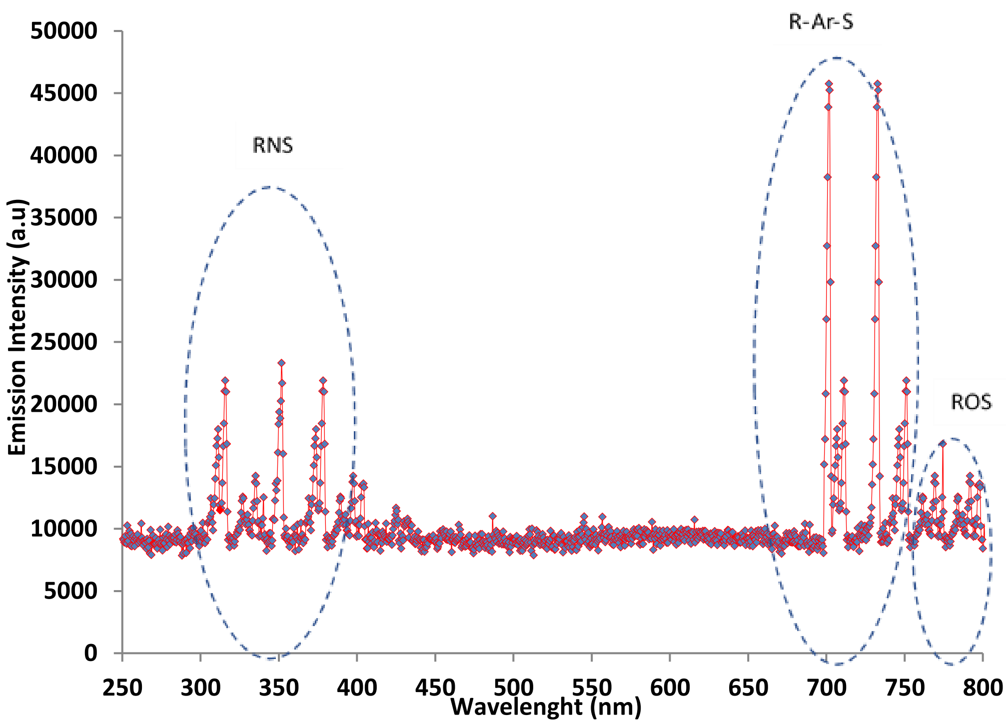
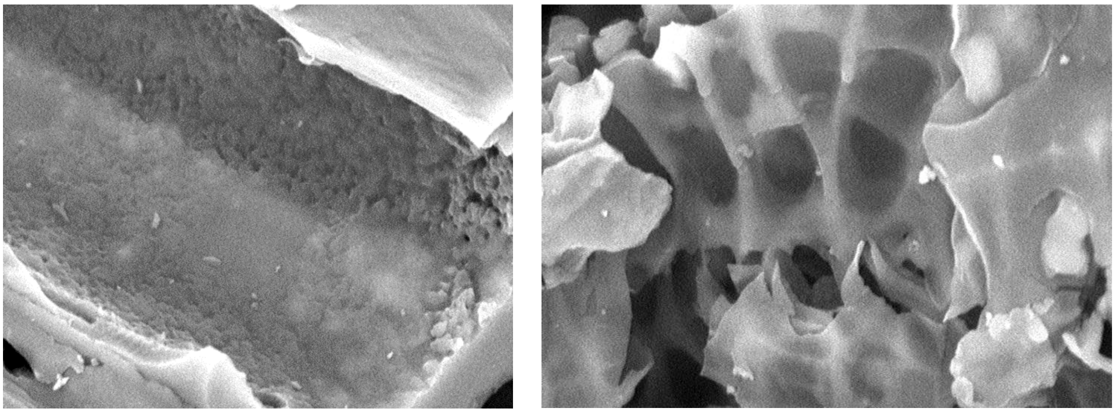


Fig. 2. Emission intensity of cold plasma

3.3 Surface Morfology

Scanning Electron Microscope (SEM) analysis was carried out to observe the surface morphology of the water hyacinth adsorbent before and after plasma jet treated with argon injection. SEM analysis can observe changes in surface topography and decrease in surface roughness during the argon injection process. SEM results of the water hyacinth adsorbent surface before and after plasma treated can be seen in Figure 3.



(a) (b)

Fig. 3. SEM of hyacinth adsorbent (a) without Cold Plasma Treated and (b) with Cold Plasma Treated

Based on Figure 3, the surface texture of the water hyacinth adsorbent without plasma jet treated is smoother, whereas after plasma jet treated the texture becomes rougher, which leads to the formation of a graded structure. Due to plasma-treated water hyacinth adsorbents occur due to the etching process, where the injected plasma hits the surface of the adsorbent, resulting in collisions that cause contour changes. The collision produces heat which makes the polymer bonds on the surface of the water hyacinth adsorbent, so that it appears graded or peeled [20]. The roughness formed indicates a strong interaction between reactive species and electrons between the plasma and the surface of the hyacinth adsorbent. The rougher the surface, the more reactive the surface of the hyacinth adsorbent exposed to plasma radiation. The surface of hyacinth adsorbent that is exposed to cold plasma discharge will experience a change in its hydrophobic nature to hydrophilic [16]. The adsorption capacity using water hyacinth adsorbent depends on activation because plasma creates more active sites. The maximum adsorption capacity (q_e) is usually in the range of 50–150 mg/g and compared to conventional adsorbents such as activated carbon and zeolite up to 200 mg/g and bentonite ranging from 10–50 mg/g [29]. Water hyacinth adsorbent without cold plasma treated can be used for 1-2 weeks before its adsorption capacity decreases significantly and depends on the type of contaminant. Plasma-Treated water hyacinth adsorbent: Can be used longer, around 2-4 weeks, with minimal regeneration or even longer if the adsorbent can be regenerated efficiently [30].

3.4 FTIR Spectroscopy

Based on Figure 4, IR spectrum analysis provides valuable insight into the molecular composition of the hyacinth adsorbent examined. One important observation is the presence of a spectrum peak with a very high intensity around 1730 cm^{-1}, which indicates the presence of carbonyl C=O stretching. This carbonyl group is commonly found in various molecular structures. Peak 1730 cm^{-1}: Indicates carbonyl stretching (C=O), which is very important because it indicates the presence of functional groups such as esters, aldehydes, or ketones in the composition of water hyacinth adsorbent and its prominent presence in the spectrum underlines its significance in the chemical composition of hyacinth adsorbent [31]. Furthermore, the IR spectrum shows a strong absorption band at 1260 cm^{-1}, which indicates the presence of C–O stretching vibrations. Peak 1260 cm^{-1}: Indicates C–O stretching, which is often found in ether or ester group structures, indicating the presence of oxygenation on the adsorbent surface. The double peak intensity of 700 cm^{-1} indicates the presence of two different types of vibrations in the molecule, with one of the vibrations showing greater strength or intensity than the other. Peak 700 cm^{-1}: Indicates molecular vibrations with two different types of vibrations, providing insight into the structure of complex molecules [32]. In particular, the aromatic ring peaks at 3621 cm^{-1} and 1601 cm^{-1} (for the plasma jet treated) as well as at 3621 cm^{-1} and 1608 cm^{-1} (for the untreated plasma jet) provide further contributions to the complex molecular characterization. At 3621 cm^{-1} and 1601 cm^{-1} (plasma-treated): Indication of the presence of aromatic rings that experience changes in intensity or peak position due to plasma treated. At 3621 cm^{-1} and 1608 cm^{-1} (untreated): Indicates aromatic rings that are more stable or not affected by plasma treated. Additionally, the IR spectrum shows variations in the intensity of the peaks at 1069 cm^{-1} and 1139 cm^{-1} after plasma treated, indicating an increase in C–O stretching vibrations compared to the untreated hyacinth adsorbent. Variations in the peaks 1069 cm^{-1} and 1139 cm^{-1}: Shows an increase in C–O stretching after plasma treated, which indicates an increase in polar groups and a possible increase in hydrophilic properties. Furthermore, the peaks at 2947 cm^{-1} and 1450 cm^{-1} correspond to specific clusters, adding to a more comprehensive understanding of the molecular structure of the hyacinth adsorbent. The variations in the peaks at 2947 cm^{-1} and 1450 cm^{-1} indicate the presence of aliphatic clusters or groups, which may be part of the basic structure of the adsorbent. To understand the chemical changes on the activated hyacinth adsorbent surface, an FTIR spectrometer was used to investigate the bound functional groups. In the spectrum shown in Figure 4, the plasma-treated sample shows several definitive peaks located at around 1400 cm^{-1}, which correspond to the stretching absorption of C–N. Untreated activated hyacinth adsorbent also shows a peak at 1400 cm^{-1}, which may indicate C=C stretching. C=C stretching generally has an absorption band around 1400-1600 cm^{-1}. The increase in intensity at 1400 cm^{-1} (C–N) and 1069 cm^{-1} (C–O) after plasma treated indicates significant modifications on the adsorbent surface, including oxidation or addition of nitrogen groups. The FTIR peak observed in the treated sample at 1400 cm^{-1} may overlap with C–N, because the peak at 1400 cm^{-1} in the spectrum of the treated sample is stronger than that of the untreated sample. Peak 1400 cm^{-1}: In plasma-treated samples, it indicates a more dominant C–N stretching. In untreated samples, the same peak may indicate C=C stretching, but its intensity is weaker compared to treated samples. This indicates a modification of the chemical structure, such as the addition of C–N groups after plasma treated.

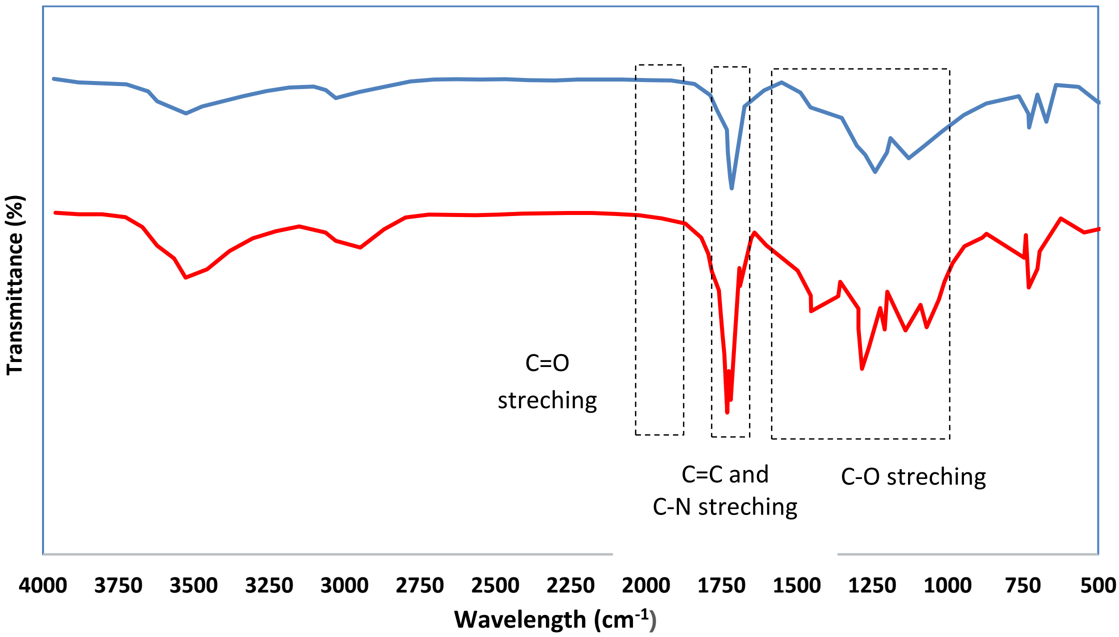


Fig. 4. FTIR Spectra of Untreated (——) and Cold Plasma Treated (——) Activated Hyacinth Adsorbent

3.5 COD, BOD and TDS Test

The COD value is one of the parameters for measuring water pollution caused by organic materials that have decomposed microbiologically, thereby reducing dissolved oxygen levels in the water. Analysis of BOD levels can indicate the need for oxygen by microorganisms to decompose organic substances dissolved or suspended in water. Table 1 shows that capacity of hyacinth adsorbent on COD, BOD, TDS rainwater purification.

Table 1
Rainwater characterization

Characterization	Without Plasma Jet Treated (mg L^{-1})	With Plasma Jet Treated (mg L^{-1})
COD	32.44	16.22
BOD	20.26	7.49
TDS	180.46	120.22

Table 1 shows the reduction in COD and BOD along with plasma jet treated. These results confirm that exposure to plasma jets produces oxidizing species capable of degrading organic matter content in rainwater as well as the presence of RNS and ROS in solution. The table also shows that once the radicals from the discharge come into contact with the solution, the ionic species responsible for the increase in conductivity and TDS are produced. The presence of these ions confirms the fact that plasma is an ionizing medium. This radical group continues to carry out the same actions after treated [33].

Cold plasma, is known to produce reactive species such as free radicals, ions, and UV radiation, which can play a significant role in breaking down organic pollutants and other contaminants in water. Reactive oxygen species (ROS) like hydroxyl radicals (*OH) and ozone (O_3) generated by plasma can react with organic pollutants in wastewater, leading to the breakdown of complex molecules into simpler, often less harmful compounds [34]. This process reduces COD and BOD by lowering the oxygen demand required to oxidize organic matter. High-energy electrons in plasma may break the chemical bonds in organic contaminants, leading to their decomposition [31]. Plasma treated can degrade toxic organic compounds, making the water more amenable to biological treated. This reduction in toxicity can result in a decrease in BOD, as microorganisms can more efficiently process the remaining contaminants [35]. Some studies suggest that plasma can stimulate microbial activity by improving the bioavailability of nutrients or reducing inhibitory substances, further enhancing BOD reduction. Plasma treated may lead to the formation of microflocs or aggregations of particles, which can help in removing suspended solids and reducing TDS [36]. The charged particles produced in plasma may interact with pollutants, either neutralizing them or causing them to aggregate into larger particles, which can then be removed more easily. Plasma treated can modify the surface properties of contaminants, promoting the release of previously adsorbed substances, which might contribute to lower TDS and COD values [37].

4. Conclusions

Cold Plasma is an effective alternative technology for activating water hyacinth adsorbent for rainwater purification. The limitations of this study are the use of a voltage of 5.5kV, an argon flow rate of 3 L/min and heating at 600°C. Exposure to cold plasma produces RNS and ROS which can reduce COD, BOD and TDS in rainwater. Decreasing percentage of COD, BOD and TDS was 50%,63% and 33%. The use of a cold plasma will also enlarge the pores of the water hyacinth adsorbent so that it can absorb impurities in the rainwater purification process. The functional groups C=C, C-C, C=O, C-O, and C-N were also detected in the activated water hyacinth adsorbent. Cold plasma activation is known to be an energy-intensive process. Therefore, future research needs to be conducted to analyze the economic and energy feasibility of this treatment, especially when compared to conventional or renewable alternatives, to clarify the feasibility of applying this approach to larger applications. Further research is recommended to optimize plasma parameters, explore different waste materials, or expand the application to different contaminants.

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