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Development of "Hydro Pure Pro (HPP)" Water Filter Technology to Reduce Iron (Fe) and TDS Levels in Drilled Well Water

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Abstract: High levels of iron (Fe) and total dissolved solids (TDS) in well water remain a major groundwater quality problem in Indonesia. This study aimed to develop and evaluate the effectiveness of a Hydro Pure Pro (HPP) water filtration system based on a multi-stage aeration–filtration process to reduce Fe and TDS concentrations. The HPP system combines activated carbon, zeolite, silica sand, mountain sand, and a reverse osmosis (RO) unit as final treatment, with a focus on assessing the effects of activated carbon raw materials (coconut shell and wood) and carbon bed thickness on adsorption performance. The results showed that coconut shell activated carbon exhibited superior performance, reducing Fe from 0.606 mg/L to 0.135 mg/L (77.72%) and TDS from 540 mg/L to 390 mg/L (27.8%) at a thickness of 20 cm. Increasing the carbon thickness to 30 cm improved removal efficiency to 79.9% for Fe and 28.7% for TDS, after which performance tended to stabilize. This improvement is attributed to the higher specific surface area and well-developed microporous structure of coconut shell activated carbon, which enhances Fe^{2+} adsorption through ion exchange and surface functional group interactions. In conclusion, the HPP system demonstrates high effectiveness and economic feasibility, making it a promising filtration technology for improving the quality of borehole water in community settings.

Keywords: Activated carbon; Appropriate technology; Hydro Pure Pro (HPP); Iron content; Slow Sand Filter (SSF); Total Dissolved Solids (TDS); Water filtration

Introduction

Access to clean and safe drinking water remains a persistent challenge in many regions of Indonesia, particularly in rural and infrastructure-limited areas where drilled wells serve as the primary water source (Matthies et al., 2016). Field observations and previous studies indicate that groundwater from drilled wells frequently contains elevated concentrations of iron (Fe) and Total Dissolved Solids (TDS), exceeding national drinking water quality standards (Minister of Health Regulation No. 2 of 2023: Fe ≤ 0.2 mg/L; TDS ≤ 300 mg/L). Elevated iron concentrations degrade water aesthetics, causing discoloration, metallic taste, odor, and scaling of pipes, while long-term consumption may also pose health risks (Kemenkes RI, 2022).

From a chemical perspective, dissolved Fe^{2+} under reducing groundwater conditions can be oxidized to Fe^{3+}, which readily forms insoluble iron hydroxides and precipitates. Consequently, oxidation and adsorption are recognized as key mechanisms for iron removal in water treatment processes. Activated carbon (AC) has been widely applied as an adsorbent due to its high specific surface area, abundance of surface functional groups (–OH, –COOH), and catalytic properties that facilitate the oxidation of Fe^{2+} on the carbon surface (Paredes-Doig et al., 2020). Recent studies have demonstrated that activated carbon functions not only as an adsorbent but also as a heterogeneous catalyst that

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promotes the oxidation of Fe^{2+} to Fe^{3+} on the carbon surface, facilitated by surface functional groups and porous structure (Zhang et al., 2019).

However, the catalytic and adsorption performance of activated carbon is not universal and varies significantly depending on its physicochemical characteristics (Bernal et al., 2018). Recent studies emphasize that the performance of activated carbon is strongly influenced by its physicochemical properties, including pore structure, surface chemistry, and particle configuration (Lu et al., 2014; Lai et al., 2023). In the past five years, increasing attention has been given to activated carbon derived from local biomass sources because of their low cost, environmental sustainability, and promising adsorption capacity (Wang & Kaskel, 2012; Wang et al., 2023a, 2023b). For instance, Elewa et al. (2023a, 2023b) reported that chemically activated rice husk carbon exhibited effective Fe^{3+} adsorption following Langmuir isotherm behavior and second-order kinetics, highlighting the potential of biomass-based activated carbon for metal ion removal (Sujiono et al., 2022).

In groundwater treatment systems, combining oxidation and adsorption using granular activated carbon (GAC) has been shown to significantly enhance iron removal efficiency. Thinojah & Ketheesan (2022a, 2022b) demonstrated that pre-oxidation followed by GAC filtration effectively reduced iron concentrations in synthetic groundwater. Nevertheless, recent review studies have identified a critical research gap: most investigations focus on batch adsorption or single-media systems, while limited attention has been given to real-scale filtration configurations that consider operational variables such as media thickness, flow rate, pressure drop, and multi-media integration (Pet et al., 2024a, 2024b).

In the Indonesian context, coconut shells and wood represent abundant and inexpensive biomass resources for activated carbon production. Despite their availability, systematic studies comparing the performance of coconut shell–based and wood-based granular activated carbon within multistage filtration systems remain scarce. Furthermore, there is a lack of research evaluating the influence of granular activated carbon layer thickness in integrated systems that combine aeration, mineral filter media (zeolite, silica sand, mountain sand), and reverse osmosis (RO) as a polishing stage.

This study addresses these gaps by introducing the Hydro Pure Pro (HPP) system, a multistage filtration technology that integrates aeration–adsorption–membrane processes using locally sourced activated carbon. The novelty of this research lies in the comparative evaluation of coconut shell and wood-based granular activated carbon under identical real filtration conditions, the systematic assessment of media layer thickness on Fe and TDS removal efficiency, and the integration of conventional filtration media with RO in a compact and economical design suitable for rural groundwater treatment.

This study focuses on evaluating the performance of activated carbon in a multistage filtration system. First, the adsorption characteristics of coconut shell–based activated carbon are compared with those of wood-based charcoal, with emphasis on differences in microstructural properties and surface functional groups that influence adsorption behavior. Subsequently, the effect of granular activated carbon layer thickness variations (10, 20, 30, and 40 cm) on the removal efficiency of Fe^{2+} and total dissolved solids (TDS) is assessed.

Thus, this research is expected to not only provide efficient and economical water filtration technology solutions, but also enrich the scientific literature on the adsorption mechanism of local activated carbon in the context of real filtration.

Method

This research is a laboratory experimental study using a quantitative approach aimed at analyzing the effects of different types of activated carbon materials (coconut shell and wood) and filtration media thickness on reducing iron (Fe^{2+}) and total dissolved solids (TDS) levels in well water. The experimental design follows a comparative method with different treatments applied to activated carbon media types and thicknesses, while other parameters are kept constant (Torres et al., 2023).

The study was conducted between July and December 2025. Water samples were collected from a partner's borehole located at the Az-Zahra Islamic Boarding School in Gunung Bagek, Santong Village, Terara District, East Lombok. Filtration and laboratory analysis were performed at the Chemistry Laboratory of the Faculty of Science and Technology, Mandalika University of Education, Mataram. The materials used in the study include granular activated carbon (Carbonex) derived from coconut shells and wood charcoal (12-40 mesh), zeolite (12-20 mesh), silica sand (12-20 mesh), mountain sand (16 mesh), gravel, and well water from the Az-Zahra Santong Terara Lotim pumps.

Chemical solutions used include FAS solution (10 ppm, 15 ml), HNO_3 (3 ml), KCNS (5 ml), and sufficient distilled water (Verma et al., 2017). The tools utilized in the study include an HPP prototype filtration system consisting of a 1-meter, 4-inch PVC filtration tube, a mini pump, ½-inch pipe, stopcock, pipe connections, pipe caps, and a filter housing with reverse osmosis (RO) membranes (0.1 µm and 0.3 µm), as well as beaker glasses, measuring flasks, stopwatches, a UV-Vis spectrophotometer (Thermo Scientific GENESYS 10S UV-Vis), an Iron Test Kit (Hanna - Iron (Fe^{2+} & Fe^{3+}) Chemical Test Kit - Hi3834), a TDS and pH meter (NOYAFANF-EZ9908 series), and digital scales from the Jeyko brand.

Based on the materials, equipment, and analytical procedures described above, the overall research workflow—from sample collection to data analysis—is summarized schematically in the flowchart shown in Figure 1.

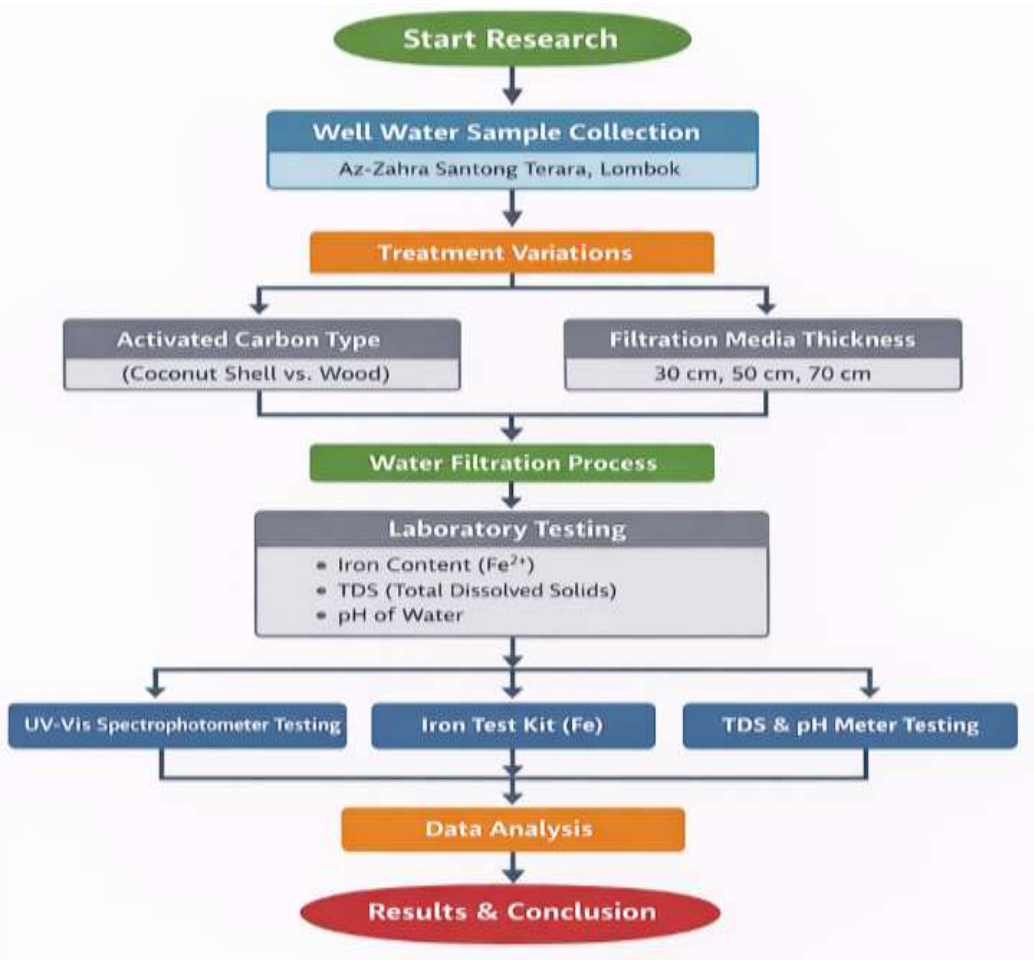

Figure 1. Research methodology on water filtration using activated carbon

Research Procedures

The research followed structured stages covering initial water sampling and testing, HPP prototype assembly, filtration media optimization, and quantitative evaluation of Fe and TDS removal, as presented in Table 1.

The study began with the collection of borehole water samples, which were analyzed to determine baseline water quality parameters, including iron (Fe), total dissolved solids (TDS), and pH prior to treatment. Subsequently, a Hydro Pure Pro (HPP) filtration system was assembled, consisting of a venturi aeration. of a venturi aerator from 1/2-inch PVC pipe, which is installed in the water line leading to the reservoir. A T-joint is installed in the center of the pipe, connected to an air hose with a diameter of approximately 0.5 cm and angled at approximately 45°. When pressurized water flows through the narrowed section of the pipe, air is automatically drawn into the water flow and forms fine bubbles in the reservoir. This system serves to increase dissolved oxygen (DO) levels before the filtration stage is carried out. Figure 1 shows the working mechanism and how to install the aerator in the water tank, can be shown at Figure 2.

The unit designed to enhance dissolved oxygen levels and a vertical filtration column containing layered media, including gravel, mountain sand, silica sand, activated carbon, and zeolite (Aziz et al., 2021). The next phase involved a comparative evaluation of two types of granular activated carbon coconut shell based and wood based each tested in triplicate to assess their adsorption performance for Fe and TDS removal. After identifying the best performing carbon type, an optimization experiment was conducted by varying the activated carbon layer thickness from 5 to 40 cm to determine the configuration that yields the highest filtration efficiency. Effluent from the HPP column was subsequently treated using a reverse osmosis (RO) unit equipped with a 0.1 µm membrane as a final polishing step to further remove dissolved ions and fine contaminants. System performance was evaluated based on reductions in Fe and TDS concentrations under controlled flow conditions, using 10 liters of aerated water per test to ensure consistent experimental conditions, shown at Figure 3.

Table 1. Experimental stages and procedures

Stage	Description
Sampling & Baseline Testing	Borehole water samples were collected and analyzed for Fe, TDS, and pH to establish baseline water quality prior to treatment.
HPP System Assembly	A Hydro Pure Pro (HPP) filtration system was assembled, consisting of a venturi aeration unit and a vertical filtration column containing gravel, mountain sand, silica sand, activated carbon, and zeolite.
Activated Carbon Type Comparison	Coconut shell–based and wood-based granular activated carbon were tested in triplicate to evaluate adsorption performance for Fe and TDS removal.
Activated Carbon Thickness Optimization	The best-performing carbon type was further tested at varying layer thicknesses (5–40 cm) to determine the optimal filtration efficiency.
RO Integration	Effluent from the HPP column was passed through a 0.1 µm reverse osmosis (RO) membrane to enhance dissolved ion and fine contaminant removal.
Performance Testing	Filtration effectiveness was evaluated based on Fe and TDS reduction under controlled flow conditions using 10 L of aerated water per test.
Parameter Measurement	Fe was measured using an Iron Test Kit and UV–Vis spectrophotometry; TDS was measured using a digital meter; supporting parameters (pH, DO) were recorded as needed.
Data Analysis	Statistical analysis included One-Way ANOVA for thickness variation and t-test for carbon type comparison; removal efficiency was calculated from initial and final concentrations.

The aerated water flows through a series of vertically arranged filtration media consisting of gravel, silica sand, activated carbon, and zeolite. The filtered water is then directed to a housing unit equipped with a Reverse Osmosis (RO) membrane (0.1 µm) for final purification, ensuring improved removal of dissolved and suspended impurities (Julyane & Rahmawati, 2024).

Parameter measurements were conducted using an Iron Test Kit and UV–Vis spectrophotometry for Fe analysis, as well as a digital TDS meter, while supporting parameters such as pH and dissolved oxygen (DO) were recorded to support process mechanism interpretation (Cheng et al., 2022). Statistical analysis was performed using One-Way ANOVA to examine the effects of activated carbon thickness and a t-test to compare the effectiveness of carbon types, with removal efficiency calculated based on differences between initial and final concentrations (Prayoga & Wulandari, 2024).

Figure 2. Venturi aerator on water tank

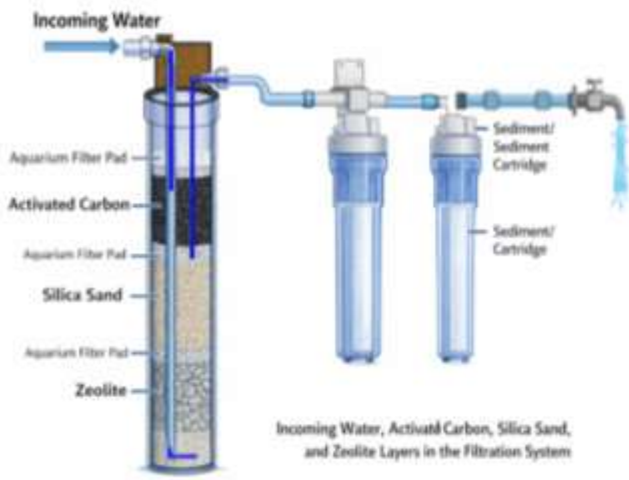

Figure 3. Installation circuit on HPP filtration system

The percentage decrease in Fe levels is calculated using the formula:

$$\text{Effectivinass} = \frac{C_{\text{initial}} - C_{\text{final}}}{C_{\text{initial}}} \times 100\% \tag{1}$$

Information:
$C_{initial}$ = Concentration before filtration
C_{final} = Concentration after filtration

Result and Discussion

Initial Test of Activated Carbon Type

The initial testing focused on identifying the type of activated carbon that was most effective in reducing total iron (Fe) and total dissolved solids (TDS) levels. Two types of activated carbon were tested: coconut shell–based and wood–based activated carbon, both used in granular form with a media thickness of 20 cm. The comparison of the test results for both types of activated carbon is presented in Figure 4.

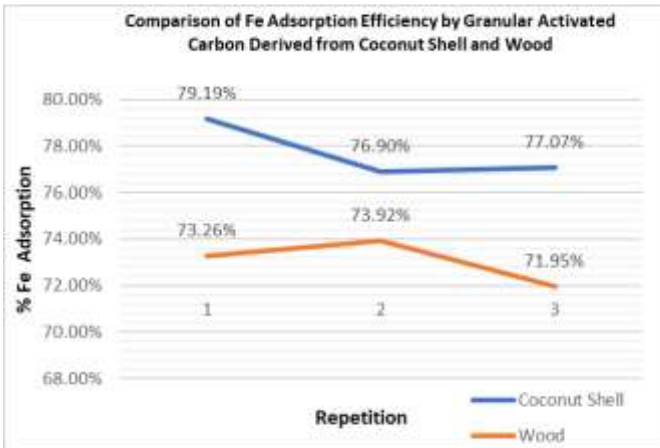

Figure 4. Fe adsorption using coconut shell and wood activated carbon on HPP Filter

The Figure 4 shows a comparison of the adsorption effectiveness of Fe^{2+} ions by granular activated carbon from two different raw materials, namely coconut shell and wood, in three repetitions. In general, activated carbon from coconut shell showed consistently higher adsorption performance, with an average effectiveness of 77.72%, compared to activated carbon from wood which only reached 73.04%.

This difference is due to the more dominant microporous structure of coconut shell activated carbon, which provides a larger specific surface area and increases the number of active sites for adsorption of Fe^{2+} ions. Surface functional groups such as –OH, –COOH, and C=O also play a role in forming electrostatic interactions with dissolved metal ions, thereby increasing the adsorption capacity (Onigemo et al., 2024).

Although there was a slight fluctuation between repetitions (76.90–79.19%), the data pattern showed good stability of filtration performance, indicating the resistance of the adsorbent to surface saturation within a relatively short contact time. In contrast, activated carbon from wood showed a decrease in effectiveness at the 3rd repetition (71.95%), indicating pore blockage and lower surface regeneration ability (Sun et al., 2020).

Thus, these results confirm that coconut shell activated carbon is superior chemically and morphologically for the process of reducing Fe levels in drilled well water, especially when applied in a layered filtration system such as Hydro Pure Pro (HPP).

In addition to their effectiveness in reducing Fe levels, the two types of activated carbon were also tested for their ability to reduce Total Dissolved Solids (TDS). The results of the TDS reduction test are presented in Figure 5.

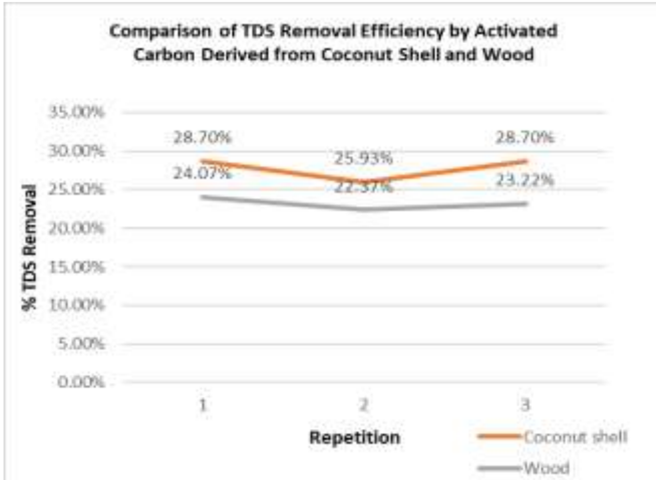

Figure 5. Comparison of TDS adsorption capabilities by coconut shell and wood activated carbon on HPP filters

The data at Figure 5 shows that granular activated carbon from coconut shells has an average TDS reduction effectiveness of 27.78%, while activated carbon from wood only achieved 23.22%. Although the difference is not as significant as in the Fe^{2+} parameter, this trend still demonstrates the structural superiority of coconut shell activated carbon in the solute adsorption process.

Chemically, the TDS reduction capability is lower than Fe because TDS consists of inorganic ions such as Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-}, SO_4^{2-}, and HCO_3^{-}, not all of which can be adsorbed through physical mechanisms. The main mechanisms that occur are electrostatic adsorption and weak ion exchange, where the effectiveness is highly dependent on the micropore surface area and the presence of polar groups on the surface of activated carbon (Yang et al., 2019).

Small fluctuations between replicates (25.93–28.70%) indicate the stability of the HPP filtration process and the media's resistance to short-term adsorption saturation. The relatively constant values indicate that the aeration–filtration system has worked effectively to remove most of the non-ionic dissolved compounds and colloidal particles that contribute to TDS.

Thus, coconut shell activated carbon is proven to be more efficient in reducing TDS than wood, mainly due to its finer microporous structure, high fixed carbon content, and more active oxygen functional groups, which together increase the adsorption capacity in the Hydro Pure Pro (HPP) system.

To further illustrate the comparative effectiveness of the two types of activated carbon in reducing Fe and TDS levels, the average results of the initial test are presented in Table 2.

The results in Table 2 show that granular activated carbon from coconut shells has a higher reduction effectiveness for both Fe (77.72%) and TDS (27.8%) compared to activated carbon from wood, which only reached 73.04% for Fe and 23.2% for TDS.

Table 2. Average results of initial tests on the effectiveness of Fe and TDS adsorption using coconut shell and wood activated carbon

Types of Carbon Active	Fe Initial (mg/L)	Final Fe (mg/L)	Fe Effectiveness (%)	Initial TDS (mg/L)	Final TDS (mg/L)	TDS Effectiveness (%)
Coconut Shell	0.606	0.135	77.72%	540	390	27.8%
Wood	0.606	0.163	73.04%	540	414	23.2%

These differences are chemically caused by differences in the microstructure and composition of the fixed carbon between the two raw materials. Coconut shell activated carbon has a higher micropore ratio, a specific surface area reaching 900–1500 m^2/g, and a harder and more stable pore wall structure, making it able to adsorb metal ions and dissolved compounds more effectively (Hidayat et al., 2013).

Meanwhile, activated carbon from wood tends to have more dominant macro and meso pores, so its adsorption capacity for small ions such as Fe^{2+} is more limited (Doczekalska et al., 2024).

The decrease in Fe content from 0.606 mg/L to 0.135 mg/L confirms the strong adsorption capacity of bivalent metal ions, mainly through complexation mechanisms and electrostatic bonds with oxygen functional groups such as carbonyl (C=O) and hydroxyl (–OH) on the surface of activated carbon. The previous aeration process converts Fe^{2+} to Fe^{3+} which is then precipitated and filtered through the HPP media, thereby increasing the total efficiency of the system.

For TDS, although its effectiveness is lower than Fe, the 27.8% value for coconut shell activated carbon still demonstrates good filtration capacity for dissolved ions and fine colloidal particles. This decrease indicates that the HPP system with a media thickness of 20 cm is practically at its optimal efficiency, thanks to a combination of physical adsorption and diffusion processes between media layers.

Thus, the results of this initial test strengthen the evidence that coconut shell activated carbon is the most potential adsorbent material for the Hydro Pure Pro (HPP)-based water filtration system, both in terms of effectiveness, performance stability, and the availability of sustainable local materials.

Thickness Variation Test of Coconut Shell Granular Activated Carbon

After determining that granular activated carbon was most effective in reducing Fe and TDS levels compared to powder and granular forms, further testing was conducted to determine the effect of filtration media layer thickness on adsorption performance. The thickness variations tested were 10, 20, 30, and 40 cm. The average results of the Fe^{2+} and TDS reduction effectiveness tests are presented in Table 3.

Table 3. Average thickness test results of coconut shell granular activated carbon

Thickness (cm)	Final Fe^{2+} (mg/L)	Effectiveness of Fe^{2+} (%)	Final TDS (mg/L)	TDS Effectiveness (%)
10	0.182	70.00	440	18.50
20	0.135	77.70	390	27.80
30	0.122	79.90	385	28.70
40	0.127	79.00	387	28.30

The Figure 6 shows the relationship between the thickness of coconut shell granular activated carbon media and the effectiveness of Fe^{2+} adsorption and TDS. It can be seen that increasing the media thickness from 10 to 30 cm is directly proportional to the increase in the reduction efficiency of both parameters. The Fe reduction effectiveness increased from 70.00% at 10 cm thickness to 79.90% at 30 cm, then relatively stabilized at 79.00% at 40 cm. A similar trend was seen in TDS, with an increase from 18.50 to 28.70%, and slightly stagnated at 28.30% at the maximum thickness.

This trend indicates that increasing the media thickness extends the contact time between water and the adsorbent surface, thereby increasing the opportunity for Fe^{2+} ions to interact with the carbon's active sites (π-electrons and functional oxygen groups).

However, after reaching a thickness of 30 cm, the efficiency increase begins to decrease due to saturation of the adsorption zone and a decrease in the concentration gradient, which causes the rate of ion diffusion to the deepest pores to decrease (Fila & Kołodyńska, 2023).

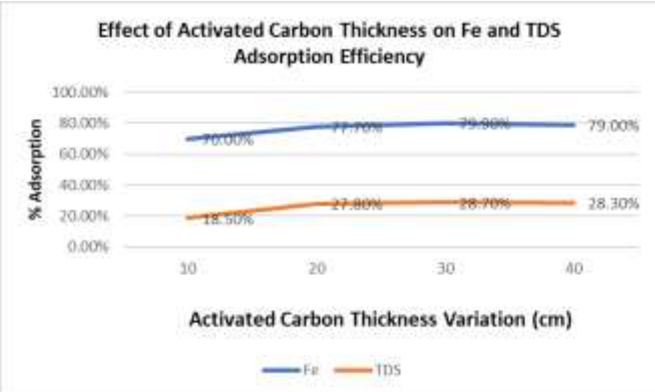

Figure 6. Fe and TDS adsorption capacity of coconut shell activated carbon at several thickness variations

For the TDS parameter, the lower effectiveness compared to Fe is due to the dominance of inorganic ions, which are not entirely physically adsorbed, but rather remain largely dissolved in the aqueous phase. Nevertheless, the reduction value approaching 30% indicates that the activated carbon medium still contributes to the removal of dissolved colloidal compounds, silica, and light anions through van der Waals mechanisms and interpore diffusion.

With these results, it can be concluded that the optimum thickness of coconut shell granular activated carbon media is 30 cm, because it provides a balance between adsorption efficiency and hydraulic efficiency of the Hydro Pure Pro (HPP) filtration system.

Conclusion

Granular activated carbon made from coconut shell proved to be the most effective in reducing Fe and TDS levels in the Hydro Pure Pro (HPP) filtration system, with optimal performance at a 30 cm media thickness. Its high microporosity and active functional groups make it superior to wood-based carbon in both adsorption capacity and filtration stability.

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Author Contributions
H.H., as the principal investigator with expertise in environmental and applied chemistry, was responsible for the research design, coordination of experimental activities, and supervision of all project stages through to final reporting; D.R.I., specializing in analytical chemistry, contributed to data processing, data analysis, and manuscript preparation; N., with expertise in public health, assisted in evaluating environmental health aspects and the application of research outcomes in community contexts; M.F.Z., an expert in electrical and information engineering, contributed to the design, assembly, and performance testing of the Hydro Pure Pro (HPP) prototype system.

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Conflicts of Interest
The authors declare no conflict of interest.

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