HIGIENE: Jurnal Kesehatan Lingkungan

Environmental Health Journal

ORIGINAL RESEARCH

Rice Husk Activated Carbon for Manganese Removal from Well Water: Effects of Activation Time

Running title: Rice Husk Carbon for Manganese Removal

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Received	Revised	Accepted	Published
21 July 2025	17 December 2025	22 July 2026	20 August 2026

Abstract

Background: Manganese (Mn) in PT. X well water was 1.61 mg/L, exceeding the Indonesian hygiene-sanitation limit of 0.1 mg/L. Objective: To determine the most effective rice-husk activated-carbon activation time for Mn removal. Methods: A pretest-posttest experiment without an untreated control compared activation for 15, 30, and 45 min at 900°C, with six replicates per group (36 pre/post samples). Mn was measured by atomic absorption spectrophotometry; pH and temperature were monitored. Kruskal-Wallis tested differences ($p<0.05$). Results: Mean pre-treatment Mn was 1.348, 1.365, and 1.364 mg/L; post-treatment values were 0.470, 0.335, and 0.077 mg/L, corresponding to reductions of 63.32%, 75.67%, and 94.17%. Groups differed significantly, and all six 45-min post-treatment values were below 0.1 mg/L. Conclusion: Activation at 900°C for 45 min achieved the greatest Mn removal.

Keywords: activated carbon; activation time; manganese; rice husk; well water

Research Highlights

- Rice husk activated carbon reduced mean manganese concentrations by 63.32%, 75.67%, and 94.17% after 15-, 30-, and 45-minute physical activation treatments, respectively.
- The 45-minute activation treatment produced a mean post-treatment manganese concentration of 0.077 mg/L, below the 0.1 mg/L regulatory limit in every replicate.
- Physical activation at 900°C provides a locally available agricultural-waste-based option for improving manganese-contaminated well water, although longer activation times warrant further evaluation.

1 Introduction

Manganese accumulation originating from agricultural activities can contaminate groundwater, particularly under environmental conditions with low oxygen levels. Such conditions may allow manganese concentrations to increase beyond thresholds established in environmental quality standards. If left unmanaged, high manganese concentrations in water may produce adverse effects, including an unpleasant metallic taste and odor in drinking water and brown stains on light-colored clothing [1].

As a mitigation measure for manganese contamination risks in industrial areas, several water-treatment methods have been developed and applied, including oxidation, aeration, and adsorption. Among these approaches, adsorption is considered a relatively simple, effective, and economical technique, particularly when a filtration medium with high adsorption capacity is used. Activated carbon is widely used because it has a large surface area and high adsorption capacity [2].

The effectiveness of activated carbon for heavy-metal adsorption has also been demonstrated in previous studies. Phuong et al. [3] used 10 L of artificial wastewater containing Fe and Mn at concentrations of 10 mg/L and evaluated seven independent treatment variables, including five combinations of limestone and rice husk activated carbon, limestone alone, and rice husk activated carbon alone. In that study, the use of rice husk activated carbon alone produced the most optimal reduction, reaching 99.8%.

The effectiveness of activated carbon in the adsorption process is closely related to its porous structure, which can retain small particles ranging from colloids to chemical compounds. Its high carbon content, approximately 85-95%, is formed through high-temperature heating. Activated carbon can also be produced from agricultural waste, making it a promising alternative because the raw material is inexpensive and renewable and may provide high carbon content, low ash content, and favorable hardness characteristics [4].

Activated carbon from agricultural waste can be produced through two main approaches, physical activation and chemical activation, each of which has distinct characteristics and effects on the quality of the resulting carbon. Physical activation is generally considered more environmentally friendly because it does not require additional chemicals and is also relatively economical and easy to implement [5]. Chen et al. [6] reported that physical activation of rice-husk-based material could produce a manganese adsorption capacity of 25.67 mg/g, higher than chemical activation using NaOH, Na2S, and HNO3.

Similar findings were reported by Monarita et al. [7], who emphasized the importance of controlling temperature and time during activation. In their study of activated carbon produced from cassava peel, the optimum condition was reported at 377°C with a burning time of 150 minutes, which produced the best adsorption performance. Yadav and Kumar [8] reported that rice husk activated carbon produced at 900°C for 60 minutes had a surface area of 561 m2/g with a carbon recovery of 20%, although increasing the burning time reduced carbon recovery.

These findings indicate that the quality and adsorption capacity of activated carbon are strongly influenced by activation temperature and duration. High temperatures combined with controlled activation times are therefore important for developing optimal porosity and a large surface area.

Based on previous studies, the present study selected an activation temperature of 900°C to optimize the characteristics of rice husk activated carbon [8]. Physical activation times of 15, 30, and 45 minutes were evaluated. The 15-minute interval below the 60-minute duration was based on Arifin et al. [9], who applied comparable time variations in ultrasonic irradiation of activated carbon produced from end-of-life rubber powder. That study was used as a reference for the time variation because the present work focuses on the basic concept that processing time can influence pore structure, surface area, and adsorption performance.

The urgency of this study arose from a water-quality problem at PT. X, which is located near agricultural land. Laboratory analysis showed a manganese (Mn) concentration of 1.61 mg/L in groundwater at the site, exceeding the maximum concentration of 0.1 mg/L specified in Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023 [10]. The elevated manganese concentration indicates the need for an appropriate water-treatment solution to reduce heavy-metal contamination and improve well-water quality at the site.

Based on the literature review, studies specifically examining the effect of rice husk activated carbon activation-time variations on manganese reduction remain limited. Therefore, this study was conducted to evaluate the effectiveness of rice husk carbon activated at a fixed temperature of 900°C for 15, 30, and 45 minutes in reducing manganese concentrations in well water at PT. X. The study was intended to provide a more detailed understanding of the relationship between activation duration and adsorption capacity and to identify the most effective activation time among the tested conditions.

2 Materials and Methods

2.1 Study design and setting

This study used an experimental pretest-posttest design without a control group to determine the most effective activation-time variation of rice husk activated carbon for reducing manganese concentrations in well water at PT. X. The experiment was conducted in 2025 at an electronics industry located in West Bandung Regency, West Java, Indonesia. Experimental activities reported in the Results section were conducted from 28 May to 2 June 2025 between 08:00 and 12:00 Western Indonesian Time (WIB). The experimental approach was selected to assess the effect of rice husk activated carbon activation time on manganese reduction through numerical pre-treatment and post-treatment measurements.

2.2 Population, sampling, and sample size

The population was all water contained in the first storage tank at PT. X Jaya, which was reported in the Methods section to have a capacity of 820 L. The sample volume was calculated from an adsorption-column volume of 8.15 L multiplied by the total pretest and post-test samples across six repetitions, resulting in 293.4 L. Water was collected using grab sampling, defined in the source manuscript as sampling at one time from the same water source. A total of 18 pretest and 18 post-test samples were examined, giving 36 samples overall. Sampling was conducted over two days with three repetitions per day.

2.3 Variables and measurements

The experimental factor was physical activation duration of rice husk activated carbon at a fixed temperature of 900°C, with three activation-time variations: 15, 30, and 45 minutes. The main outcome was manganese concentration in well water. Water pH and temperature were also measured to characterize conditions before

and after adsorption treatment and to assess whether these parameters could plausibly influence the observed manganese-removal process.

Data were collected through direct measurement. Well-water quality parameters were measured before and after treatment. Manganese concentration was analyzed using Atomic Absorption Spectrophotometry (AAS). The data-collection instruments reported in the source manuscript were an observation sheet, camera, pH meter, and thermometer. The pH meter and digital thermometer were calibrated before measurement. Manganese testing was conducted by the Ujungberung Environmental Agency Laboratory.

2.4 Statistical analysis

Data analysis consisted of univariate and bivariate analyses. Univariate analysis was used to describe manganese concentrations before and after treatment across the three activated-carbon activation durations and was presented using tables, means, and percentage reduction. For bivariate analysis, normality was assessed using the Shapiro-Wilk test and homogeneity of variance using Levene's test. Because the reported data were non-normally distributed and variances were not homogeneous, differences among treatment groups were analyzed using the non-parametric Kruskal-Wallis test. Statistical significance was defined as $p < 0.05$. Data processing and analysis were performed using Microsoft Excel and IBM SPSS Statistics version 27.

2.5 Ethical considerations

The study involved environmental well-water samples and did not report the enrollment of human participants or experimental animals. The source manuscript includes a company letter documenting acceptance of the student for field-practice activities at PT. Hana Master Jaya during the study period. A formal ethics committee approval document was not included in the source file.

3 Results

The study was conducted using well water from PT. X and focused on reducing manganese concentrations in water used for hygiene and sanitation purposes. Rice husk activated carbon was used as the adsorption medium, with physical activation-time variations of 15, 30, and 45 minutes. Experimental work was conducted from 28 May to 2 June 2025 between 08:00 and 12:00 WIB. Eighteen pretest and 18 post-test samples were examined, for a total of 36 samples. Samples were collected on two days with three repetitions per day. The measured parameters were pH, temperature, and manganese concentration.

3.1 Water pH

Water pH was measured to determine acidity or alkalinity before and after adsorption treatment with rice husk activated carbon. Measurements were performed using a previously calibrated digital pH meter to support measurement accuracy. The pH results are presented in Table 1.

Table 1. Pretest and post-test pH of PT. X well water treated with rice husk activated carbon by activation time

Replicate	15 min Pre	15 min Post	30 min Pre	30 min Post	45 min Pre	45 min Post
1	7.8	7.5	7.8	7.4	7.8	7.3
2	7.8	7.5	7.8	7.4	7.8	7.3
3	7.8	7.6	7.8	7.4	7.8	7.3
4	7.6	7.4	7.8	7.3	7.6	7.3
5	7.6	7.4	7.6	7.3	7.6	7.3
6	7.6	7.4	7.6	7.3	7.6	7.3

Replicate	15 min Pre	15 min Post	30 min Pre	30 min Post	45 min Pre	45 min Post
Mean	7.7	7.4	7.7	7.3	7.7	7.3

Source: Primary data. Activation times refer to the physical activation duration of rice husk carbon.

Table 1 shows changes in water pH between pretest and post-test measurements. Longer activation time was accompanied by a greater decrease in pH, although the magnitude of change remained small. The pH changes indicate alteration of water chemistry associated with interaction between the water and activated-carbon medium. All measured pH values remained within the 6.5-8.5 quality-standard range specified in Regulation of the Minister of Health No. 2 of 2023 [10].

3.2 Water temperature

Water temperature was measured to characterize physical conditions before and after adsorption treatment with rice husk activated carbon. Measurements were conducted directly in the field using a calibrated digital thermometer. Temperature is an important parameter because it can influence adsorption and chemical reactions during water treatment. The temperature measurements are shown in Table 2.

Table 2. Pretest and post-test temperature of PT. X well water treated with rice husk activated carbon by activation time

Rep.	Ambient °C	15 min Pre °C	15 min Post °C	30 min Pre °C	30 min Post °C	45 min Pre °C	45 min Post °C
1	24	24	25	24	25	24	25
2	25	25	25	25	25	25	25
3	26	26	27	26	27	26	27
4	24	24	25	24	25	24	25
5	25	25	25	25	25	25	25
6	27	27	27	27	27	27	27
Mean	25	25.17	25.67	25.17	25.67	25.17	25.67

Source: Primary data.

Table 2 indicates that no marked change in water temperature occurred during treatment. This suggests that the treatment did not substantially alter water temperature and that temperature was unlikely to be the main factor responsible for the observed manganese reduction under the experimental conditions.

3.3 Manganese concentration

Manganese concentration was measured to determine the effectiveness of rice husk activated carbon as an adsorption medium for reducing manganese in PT. X well water. Laboratory testing was performed using Atomic Absorption Spectrophotometry. Water samples were analyzed before and after adsorption treatment for each activated-carbon activation duration. The laboratory results are presented in Table 3.

Table 3. Pretest and post-test manganese concentrations in PT. X well water by rice husk activated carbon activation time

Rep.	15 Pre	15 Post	15 Red. %	30 Pre	30 Post	30 Red. %	45 Pre	45 Post	45 Red. %
1	1.218	0.398	67.27	1.201	0.259	78.37	1.241	0.069	94.39
2	1.232	0.413	66.42	1.280	0.278	78.27	1.261	0.072	94.28
3	1.229	0.373	69.64	1.254	0.287	77.12	1.269	0.071	94.35
4	1.480	0.552	62.70	1.487	0.417	71.96	1.492	0.086	94.22
5	1.502	0.523	65.16	1.492	0.384	74.26	1.451	0.083	94.22
6	1.425	0.559	60.74	1.474	0.382	74.04	1.469	0.077	94.58

Rep.	15 Pre	15 Post	15 Red. %	30 Pre	30 Post	30 Red. %	45 Pre	45 Post	45 Red. %
Mean	1.348	0.470	63.32	1.365	0.335	75.67	1.364	0.077	94.17

Source: Primary data. Pre- and post-treatment manganese concentrations are in mg/L; Red. = reduction.

The manganese measurements in Table 3 show substantial reductions between pretest and post-test values for all activation-time variations. The mean post-treatment manganese concentration after the 15-minute activation treatment was 0.4702 mg/L, decreasing further to 0.3349 mg/L for the 30-minute treatment and reaching the lowest mean value of 0.0772 mg/L for the 45-minute treatment. Mean manganese reduction increased from 63.32% at 15 minutes to 75.67% at 30 minutes and reached 94.17% at 45 minutes. The 45-minute group also showed consistent percentage reduction across repetitions, ranging from 94.22% to 94.58%. These findings indicate progressively greater manganese-removal effectiveness with longer activation time within the tested range.

The source manuscript reports that the Kruskal-Wallis test identified a statistically significant difference among the activation-time variations ($p < 0.05$), with the 45-minute activation treatment identified as the most effective condition among those tested.

4 Discussion

4.1 Water pH

Pretest water pH decreased between the first and second sampling days by approximately 0.2 pH units. The difference was attributed in the source manuscript to water stagnation in the pipeline because the first and second sampling activities were separated by several days. Water stagnation can reduce dissolved oxygen and create anaerobic conditions, under which microorganisms may decompose organic matter and generate acidic compounds [11].

Comparison of pretest and post-test water pH showed a decrease after treatment. The reduction tended to become greater as activated-carbon activation time increased, although the overall change remained small; the largest reported difference was 0.5 pH units.

This change may be associated with ion-exchange processes and reactions involving dissolved metal ions at the adsorbent surface. Such reactions may generate H+ ions and make the solution slightly more acidic. Patmawati [12] explains that pH influences heavy-metal adsorption because it affects electrostatic interactions between metal ions and the adsorbent surface through the concentration of H+ ions in solution. Thus, even a relatively small change in pH may reflect an active adsorption process.

4.2 Water temperature

Water temperature was measured in all samples to reduce the possibility that manganese reduction could be attributed to temperature changes rather than the activated-carbon treatment. The study observed an increase of approximately 1°C in water temperature during repetitions because measurements were conducted at different times. Nevertheless, the measured temperatures remained within the reported acceptable range of approximately ±3°C relative to ambient air temperature.

Elewa et al. [11] evaluated solution temperatures of 25, 35, 50, and 65°C during manganese and iron adsorption and concluded that water temperature can influence adsorption by increasing molecular diffusion. Higher temperature increases the kinetic energy of Mn^{2+} ions and can accelerate interactions between manganese ions and activated-carbon surfaces.

In the present study, water-temperature variation was small and did not appear to produce a meaningful effect on the adsorption process. Mn^{2+} adsorption remained stable under these limited temperature changes,

and temperature increases that did not exceed the referenced water-quality condition were not considered sufficient to cause a major change in adsorption capacity. The observed temperature fluctuations were therefore considered acceptable within the experiment and were not judged to materially compromise the interpretation of the manganese-removal results.

4.3 Reduction in manganese concentration

Laboratory manganese concentrations on the second sampling day were higher than those recorded on the first sampling day. The source manuscript attributes this difference to samples being collected at different times: the first sampling was conducted on 28 May 2025 and the second on 2 June 2025. The interval included a public holiday and weekend, during which water use at PT. X reportedly decreased. Reduced water use may cause water to stagnate in the pipeline and may lower dissolved oxygen concentrations.

Lower oxygen availability may create anaerobic conditions. Under these conditions, MnO2 (Mn4+) can be reduced through electron acceptance to dissolved Mn2+ [13]. This process provides a plausible explanation for differences in manganese concentration between the first and second sampling periods.

Based on the mean experimental results, rice husk activated carbon substantially reduced manganese concentrations. Mean initial concentrations were approximately 1.3 mg/L and declined after treatment to 0.47 mg/L for the 15-minute activation treatment, 0.33 mg/L for 30 minutes, and 0.077 mg/L for 45 minutes.

The highest manganese reduction was obtained with the 45-minute activation treatment, which achieved a mean effectiveness of 94.17%. All six measurements in the 45-minute group produced final manganese concentrations below 0.1 mg/L, the limit referenced in Regulation of the Minister of Health No. 2 of 2023 [10]. Within the tested conditions, the results indicate that longer activation duration was accompanied by greater manganese adsorption by rice husk activated carbon.

These findings are consistent with Hussain et al. [14], who reported that a rice-husk-derived biosorbent activated for 12 hours at 80°C reduced Mn2+ in water by 94.96%. The source manuscript interprets this comparison as indicating that a higher activation temperature may allow a shorter activation duration while achieving a similar manganese-removal percentage.

The interpretation is further supported in the source manuscript by Yadav and Kumar [8], who reported that increasing activation temperature and/or duration promotes pore formation, thereby increasing activated-carbon surface area and adsorption capacity. In the Discussion section of the source manuscript, activation at 900°C for 60 minutes is reported to produce a maximum surface area of 589.67 m2/g, illustrating the importance of activation conditions for pore development and adsorption performance.

The study provides repeated pretest and post-test measurements across three activation durations and monitored pH and temperature alongside manganese concentration. However, the reported design did not include a control group, and the source manuscript did not report direct characterization of the resulting activated carbon, such as BET surface area, pore-volume distribution, or surface functional groups. Consequently, the observed treatment differences support the performance of the tested activation conditions but do not directly establish the structural mechanism responsible for the differences in adsorption.

5 Conclusion

Rice husk activated carbon was effective as an adsorption medium for reducing manganese, a chemical contaminant in PT. X well water. Mean pre-treatment manganese concentrations for the 15-, 30-, and 45-minute activation groups were 1.348, 1.365, and 1.364 mg/L, respectively. After treatment with rice husk activated carbon, mean manganese concentrations decreased to 0.470, 0.335, and 0.077 mg/L, respectively. The corresponding mean reductions were 63.32%, 75.67%, and 94.17%. Based on the Kruskal-Wallis analysis

reported in the source manuscript, the 45-minute activation treatment was the most effective among the tested conditions, with a mean absolute decrease of approximately 1.287 mg/L. Future testing of a 60-minute activation period is recommended to determine whether manganese adsorption can be further improved.

6 Declarations

Ethics approval and consent to participate

The study involved environmental water samples and did not report human participants or experimental animals. Formal ethics committee approval was not reported in the source manuscript. The source file includes a company letter documenting acceptance for field-practice activities at the study site.

Consent for publication

Not applicable; the manuscript does not report identifiable individual participant information or images.

Funding

No external funding information was reported in the source manuscript. This statement should be confirmed by the authors before submission.

Competing interests

Competing-interest information was not stated in the source manuscript. The corresponding author should confirm the journal's required declaration before submission.

Author contributions (CRediT)

Specific CRediT roles were not documented in the source manuscript and should be confirmed by all authors before submission.

Data availability

All numerical results reported in this article are included in the tables; any additional study records should be requested from the corresponding author.

Acknowledgments

The authors acknowledge PT. X for facilitating field activities and the Ujungberung Environmental Agency Laboratory for manganese analysis.

Generative AI statement

Generative AI was used to assist with English-language editing, structural reorganization, and manuscript formatting. The authors reviewed the output and remain responsible for the accuracy, originality, citations, and integrity of the manuscript.

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