

Pecan Shell-Based Magnetic Biochar for Arsenic Remediation: Performance Optimization using a Fuzzy Decision Network and Response surface methodology

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The growing need for cost-effective and sustainable water treatment solutions has spurred research into agricultural waste-derived biosorbents. Various nutshells have shown promise for removing pollutants such as cadmium, lead, and mercury from contaminated water (Dias et al. 2021). Pecan nut (*Carya illinoensis*) is particularly attractive in Mexico, the world's second-largest exporter, as they are abundant, especially in arid regions experiencing water scarcity. Previous studies have demonstrated pecan nutshell's ability to adsorb heavy metals like chromium, iron, and zinc (Corral-Escárcega et al. 2017), as well as anionic dyes (Aguayo-Villarreal et al. 2017). Fuzzy Decision Networks (FDNs), offer promising solutions for handling uncertain and nonlinear relationships in various domains, such as multi-input fuzzy rules emulated network (MiFREN) (Treesatayapun 2022). Response Surface Methodology (RSM) has been successfully used to optimize arsenic removal from water through various techniques. For instance, RSM modeled the adsorption of As(III) on iron oxide granules (Tabatabaei et al. 2020). The RSM approach proved reliable and effective in determining optimal conditions for arsenic removal across different treatment methods, with high correlation between predicted and experimental results.

This research investigates the potential of magnetic biochar derived from pecan shells for arsenic remediation. Furthermore, optimization of this process is achieved using a Fuzzy Decision Network combined with RSM.

Pecan shell-based magnetic biochar for arsenic removal was synthesized via coprecipitation. The study analyzed the effects of precursor, iron salt, particle size, Fe:precursor ratio, and N₂ gas on the adsorbent properties. Adsorption capacity (q_e) was evaluated under varying arsenic concentrations, pH levels, adsorbent doses, and agitation speeds. Surface functional groups were analyzed using Fourier Transform Infrared Spectroscopy (FTIR) in ATR mode (Figure 1(a)). Ten biochar variations (FS1-FS10) and pecan nutshell (PM) were tested, and the q_e of FS1-FS10 is shown in Figure 1(b).

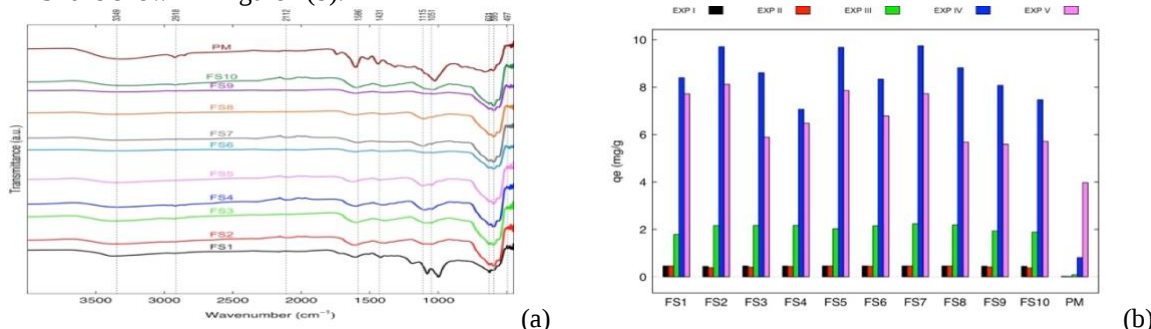


Figure 1. (a) FTIR spectra and (b) adsorption capacity using of pecan shell-based magnetic biochar (FS1-FS10).

A fuzzy-based decision-making approach analyzes results from various experimental setups to identify optimal conditions for maximizing arsenic removal. This method effectively utilizes human knowledge to enhance performance under different scenarios, contributing to the development of sustainable and efficient materials for water treatment and environmental remediation.

MiFREN uses normalized removal quality, μ_{L-Z} , as input. It employs two node functions; the second utilizes a weight vector $w = [0.5 \ 0.6 \ 0.7 \ 0.85 \ 1]^T$. Figure 2(a) illustrates the design of membership functions μ_{L-Z} .

The results underscore the effective arsenic removal of FS2, which benefits from the use of cost-effective pecan nutshell biomass as a precursor (Figure 2(b)).

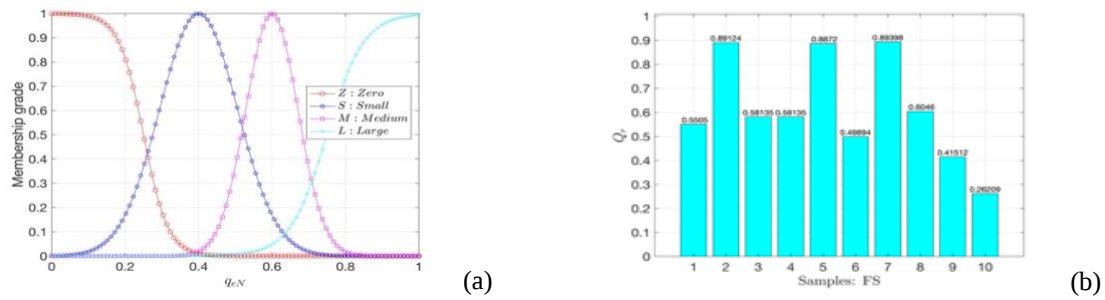


Figure 2. (a) Membership functions of MiFREN and (b) MiFREN performance index: Q_7 .

The optimal As adsorption conditions for FS2 were determined through RSM, analyzing initial As concentration (x_1), pH (x_2), and dose (x_3) at three levels plus center points (Figure 3). R software (v4.0.3) was used for analysis. The RSM model ($p < 0.05$, $R^2 = 0.9594$) demonstrates that maximizing both adsorbent dose and initial arsenic concentration is critical, as confirmed by 3D plots (Figure 3). The quadratic model described by equation Eq. 1 incorporates main effects, interactions, and quadratic terms:

$$q_e = 4.29 + 2.93x_1 - 1.24x_2 + 4.41x_3 - 1.03x_1*x_2 + 3.11x_1*x_3 - 0.97x_2*x_3 - 1.48x_1^2 + 0.82x_2^2 + 1.35x_3^2 \quad (\text{Eq. 1})$$

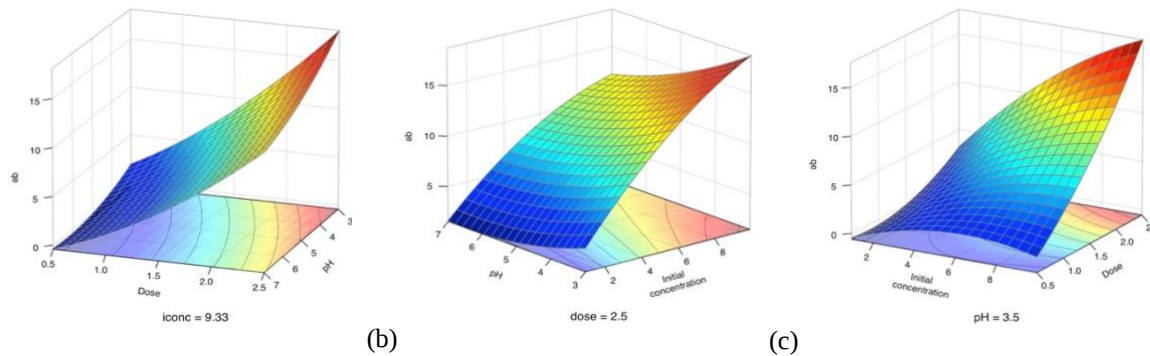


Figure 3. Surface plots of FS2 for optimal parameter values of initial As concentration, pH, and adsorbent dose.

In conclusion, the pecan shell-based magnetic biochar (FS2) demonstrates significant potential for arsenic adsorption, optimized by maximizing both adsorbent dose and initial arsenic concentration. Furthermore, the minimal dependence on pH suggests FS2's adaptability to diverse environmental conditions.

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