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Original Article

Efficiency of Eco-Friendly Surface in Removing Organic and Inorganic Pollutants from Wastewater

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ABSTRACT

Introduction: The current study investigated the use of acid-treated rice husks to remove heavy metals and organic pollutants from water containing heavy metals (R2C and Cd2) and organic pollutants (phenol and atrazine). **Methods**: The adsorption effect of acid-treated rice husks was compared with other adsorbents such as activated carbon, chitosan, and bentonite clay. **Result:** both acid-treated rice husks and activated carbon were highly efficient materials, and thus, rice husks were established as a cost-effective alternative. It was revealed that acid treatment of rice husks enhanced adsorption capacity by half, and lead removal was nearly doubled. The most effective pH value for optimizing organic pollutants and heavy metals while minimizing conditions was found to be 6.5. Regarding the temperature findings, the data revealed a minor increase in temperature; nevertheless, the result was not statistically significant, even if the temperatures became more efficient. When compared to activated carbon, chitosan, and bentonite clay, acid-treated rice husks demonstrated high removal performance, making them a very cost-effective raw material. Finally, the presence of active functional groups that transfer the action of rice husks to pollutants was established by adsorption processes studied using Fourier transform infrared spectroscopy (FTIR) and BET (Brunauer-Emmett-Teller) surface area. **Conclusion:** Therefore, it has been demonstrated that this technique, which entails removing at least one acid-treated rice husk, is more effective at treating industrial wastewater than previously documented and widely used technologies like flocculation, coagulation, and reverse osmosis. It also offers a safe and sustainable substitute for conventional water quality methods.

***Keywords:** Acid Treatment; Adsorption; Heavy Metal Extraction; Rice Husk; Water Purification*

Introduction

Water pollution is a global environmental concern that recognizes no boundaries. The Tigris and Euphrates rivers in Mesopotamia, Iraq, which supply the majority of the country's water, are heavily polluted. Heavy metals, organic contaminants, and agricultural runoff all contribute to the decline of water quality in these areas. People and animals are at risk of getting sick and dying if they are exposed to these and dangerous chemicals as shown by Environmental studies (Hasan & Taleb, 2020; Al-Sudani, 2021; & Jameel, 2022; Mohammed *et al*. 2024). The resolution of these problems has generated opportunities that can be converted into solutions for environmentally friendly and cost-effective water treatment. Filtration is basically the technique that allows for compactness in transport

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due to its simplicity and high efficiency (Almuslamawy *et al.,* 2023; Almuslamawy *et al.,* 2023). Agricultural wastes, in particular, rice hulls, are among the natural materials that are the latest to be accused. On top of that rice husk is also a renewable resource which is an inexpensive agro-waste residue that has been employed to filter out organic compounds, heavy metals, and toxic elements successfully from contaminated water (Hu *et al.,* 2020; Mouhamad *et al.* 2019). The reasoned is because of cellulose, lignin, and silica along with some other substances that are in its chemical. Rice husk becomes a high-tech material for pollutants buffering in addition to the thermal and chemical treatment techniques introduced to make it more efficient (Trivedi *et al.* 2025; Yefremova, *et al.* 2023). The acid-treated rice husk also shows a big breakthrough in this research when it has recorded the capability of removing heavy metals such as lead and cadmium which are the main contaminants of Iraq's water systems and the implementation of this can be prompted in other countries as well (Liu, *et al.,* 2022; Rezooqi, Mouhamad & Jasim, 2021). According to the analysis of the chemical constituency of rice husk, silica (SiO_2), cellulose, and lignin are the dominant components, which give rise to the high silica content of around 90%, and, thus, the main attributes of durability and strength are the two cornerstones of this material's performance in water treatment applications (El-Sheikh *et al.* 2013). The rice husk is composed of cellulose and lignin, improving the surface reactivity of rice husk and forming more adsorption sites to adsorb harmful contaminants, such as heavy metals and organic pollutants (Wang *et al.,* 2020). Furthermore, the effect of heat on surface area and porosity control in rice husk greatly impacts absorption efficiency. Even though the surface area of untreated raw rice husk is great, in practical applications for the adsorption of pollutants, thermal activation or chemical modification may increase the surface area, making it capable of adsorbing a wide range of pollutants (Garg, Gaur & Chauhan 2023). where rice peel contains cellulose and lignin that improves its surface interaction [and creates] more binding sites to absorb harmful pollutants such as heavy metals and organic pollutants (Raji *et al*. 2023)**.** Furthermore, heat is used to change the surface area and porosity of rice peel, which significantly affects the absorption effectiveness. Although raw rice peel has a small surface area, thermal activation or chemical processing can significantly increase this area, enhancing its ability to absorb a variety of pollutants (Garg, Gaur & Chauhan 2023). Research has also shown that rice peel is able to absorb both inorganic pollutants (lead and cadmium) (Liu *et al.,* 2022) and organic pollutants (pesticides and phenols). Therefore, chemical treatments (by acid or alkali processes) amend these active functional groups to further enhance the adsorption property of rice husk, enhancing it for water cleansing application tremendously (Liu *et al.,* 2022). The objective of this study is to assess the effectiveness of rice husk as an adsorbent in the treatment of industrial wastewater, particularly for the removal of heavy metals and organic contaminants. The study seeks to offer an affordable and eco-friendly approach to enhance water quality in areas heavily impacted by industrial pollution.

Materials and Methods

This study contains, Rice husk was used as an input to filter industrial wastewater containing complex composition (phenol, atrazine), exposure to hazardous (lead and cadmium). The agricultural product, rice husk, was prepared by the Iraqi Rice Mill Company. Then exposed to air and peeled for a whole day at 60 °C. An oven removes all moisture from the cause. After that, chemical hulling of rice with 1 M hydrochloric acid solution. This method can not only remove the surface and regenerate the materials, but also remove impurities (Liu *et al.,* 2022). Commenting on the work of Kaur *et al.,* 2023, to try to object to the optimum (pH 6.5) is the pH in the solution and adjust it to the constant value using a pH meter. Our proprietary solutions of lead nitrate (Pb (NO3)2) and cadmium chloride (CdCl2) at a concentration of 100 mg/L address wastewater contaminated with strong metals. Zeng et al reported that in most cases, they are a result of industrial activities (Zeng *et al*. 2012). AAS used before and after mineral lenses in the solutions in the manner done by Okoro *et al.,* (2022). We have done this only recently with phenol and atrazine at total concentrations between 10 and 100 mg/L according to the methodology described by Yadav, Sharma and Verma (2023), to portray the biodiversity in polluted water. In line with the work by Garg, Gaur and Chauhan 2023, the concentration of CO2 (both phenol and atrazine) was recorded by UV-vis spectroscopy while taking replicas during and after stabilizing in the solution. Rice husk was washed by natural hydrophilic impurities via deionizer, then lead and cadmium were quantified in their supernatant by atomic absorption spectroscopy (AAS), and finally, dried first in air and then in an oven at 60 °C. The content of lead and cadmium in the supernatant was determined with AAS. Using UV-vis spectrophotometry, traces of atrazine and phenol were detected. Surface area and porosity of rice husk are now to be carried out by the Brunauer-Emmett-Teller (BET) method. Studies the mixing property of the material. Ultrafast atomic absorption spectroscopy was used to determine the amount of lead and cadmium. Atomic absorption spectroscopy was used in the measurement of the content of lead and cadmium in the supernatant dried in an oven at 60°C. Garg, Gaur & Chauhan 2023, Measurement of lead and cadmium in Electron Ultrafast Charger. Atomic absorption spectrometry was used for the determination of lead and cadmium in the supernatant dried both in open air and oven at 60°C. (Hu *et al.,* 2022) In the year 2020, Fourier transform infrared spectroscopy (FTIR) was adopted to study the interface of rice husk, space on experimental groups like hydroxyl (-OH), carboxyl (-COOH), and aromatic rice. As reported by Yefremova et al. (2023), this molecule interacts with the new groups by either Van Der Waals' forces, Trophic bonds, Chelation, or Magnetic attraction. This allows integration based on these multiple groups. The input energy (%) is obtained by multiplying [(C_initial - C_final)/C_initial] by 100. If the initial concentration of the pollutant is the C-terminal, then the concentration after adsorption. Data were analyzed using one-way analysis of variance (ANOVA) to evaluate the effect of rice hulls (unmilled and acid-treated) on the ability to neutralize. A *p*-value < 0.05 was considered significant. All experimental data were analysed using one-way analysis of variance instead of contrasting the absorbance between different versions (untreated rice hull, untreated rice hull, and acid-treated rice hull). If the *p*-value was less than 0.05, it was considered significant.

Results

Figure 1 makes it evident that, in comparison to the untreated form, acid-treated rice husk (RH) has a much higher adsorption efficiency for organic pollutants like phenol and atrazine as well as heavy metals like lead and cadmium. Initially, the concentration is 100% for lead (Pb2+). For untreated RH, the adsorption effectiveness is around 60%; for acid-treated RH, it is approximately 90%. Figure 1 clearly shows that acid-treated rice husk (RH) has a much better adsorption efficiency for heavy metals like lead and cadmium as well as organic pollutants like phenol and atrazine when compared to the untreated form. The lead level is 100 percent at first. For untreated RH, the adsorption effectiveness is around 60%, whereas for acid-treated RH, it is 90%. The main causes of this enhanced adsorption capacity were the larger surface area and the presence of functional groups like hydroxyl (-OH) and carboxy (-COOH). Such compounds help to establish more robust bonds with pollutants, which leads to increased adsorption effectiveness for all types examined. Figure 1 illustrates that when it comes to absorbing organic contaminants and toxic substances, acid-treated rice husk outperforms unprocessed rice husk. The primary source of this functionality improvement is the increased surface area and functional groups brought about by the application of acids, therefore encourages interaction with pollutants (Jain *et al.,* 2022).

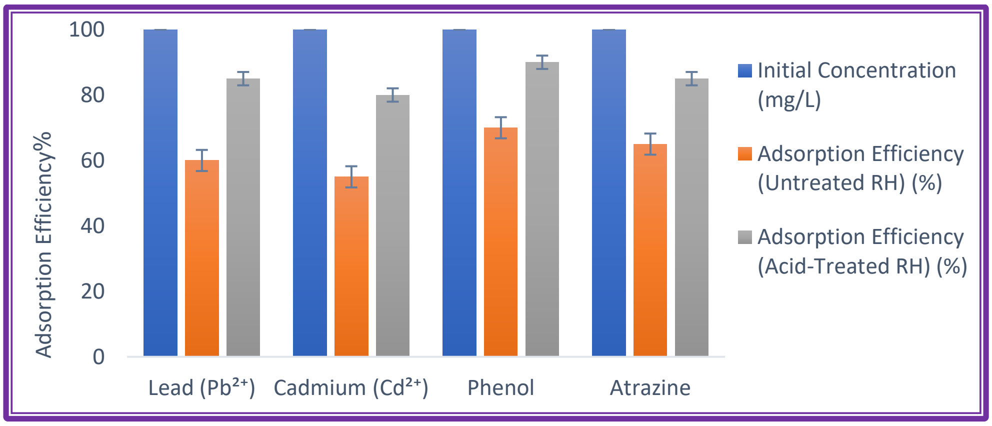

Figure 1: *Adsorption effectiveness of rice husk for organics and heavy metals contaminants*

Figure 2 illustrates the effect of solution pH on the adsorption capacity of rice husk for heavy metals (Pb^{2+} and Cd^{2+}) and organic contaminants (atrazine and phenol). All adsorption rates are quite depressed at pH 4.5: atrazine nearly 50%, phenol about 60%, Cd^{2+} at 55%, and Pb^{2+} at 65%. It's almost flat out across the piece with the surface temperature so near 90% for Cd, near 80% for phenol, and nearly 85% for atrazine. Around 80%: Therefore, the ideal pH when using rice husk in the blending process is 6.5. The situation deteriorates when we examine at pH 8.5, with atrazine falling to approximately 60%, phenol to about 70%, cadmium to about 65%, and lead to around 75%. According to these results, rice husk functions best in environments that are slightly acidic to neutral, most likely due to the fact that surface charge interactions are at their greatest around pH 6.5. This has been supported by several researchers who reported that the sorption capacity of rice husk does vary with the pH of the solution, especially those of organic pollutants such as atrazine and phenol and heavy metals like Pb2+ and Cd2+. For example, it was reported that the optimum pH for the sorption when using rice husk is 6.5 because surface charges engage with impurities at this pH in a way that optimises the process. As evidenced in the studies of Batool et al., 2024, an optimal surface charge on rice husk gives an efficient maximum of metal sorption at that pH value; the performance becomes a bit reduced at higher pH values due to the ionic forms change of metals. In a related development, Hu *et al.*, 2022 found that rice husk also performed optimally in a moderately acidic environment regarding organic pollutants, which are based on the facts about phenol and atrazine to make sense that pH 6.5 is the best range.

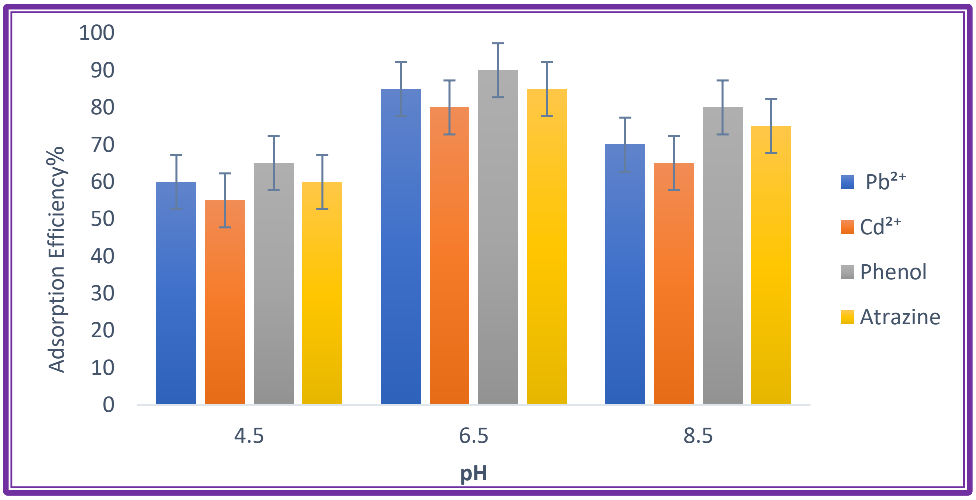

Figure 2: *The impact of ph on acid-treated rice husk adsorption efficiency*

These and other temperature-dependent interaction behaviours appear in Figure 3 for some specific pollutants: Pb2+, Cd2+, phenol, and atrazine are middle four. Phenol is about 85% and atrazine 78%. The temperature-induced increment was meagre for Pb2+ to 82% at 35°C and remained almost constant for Cd2+ at 76%. Phenol jumped to ~ 88% while atrazine fell to 77%. The slight increase in the adsorption of Pb2+ and phenol towards higher temperatures seems to indicate that how they interact with the surface of the catalyst gets hotter, and hence the adsorption capacity rises. However, not for Cd, it is of insufficient temperature change to matter much about the adsorption process with Cd. The small decrease in effectiveness for atrazine at 35°C would suggest that it is reacting with the chemical-the adsorbent becomes less stable as the temperature increases. This result is in agreement with those reports by Yadav, Sharma and Verma (2023), and others, who showed that optimal penetration occurs at neutral pH values, which enhances efficient pollutant-skin interactions. All in all, although there was only a slight rise in exposure intensity, these changes were not significant, indicating that it is body mechanics that is responsible for the induction.

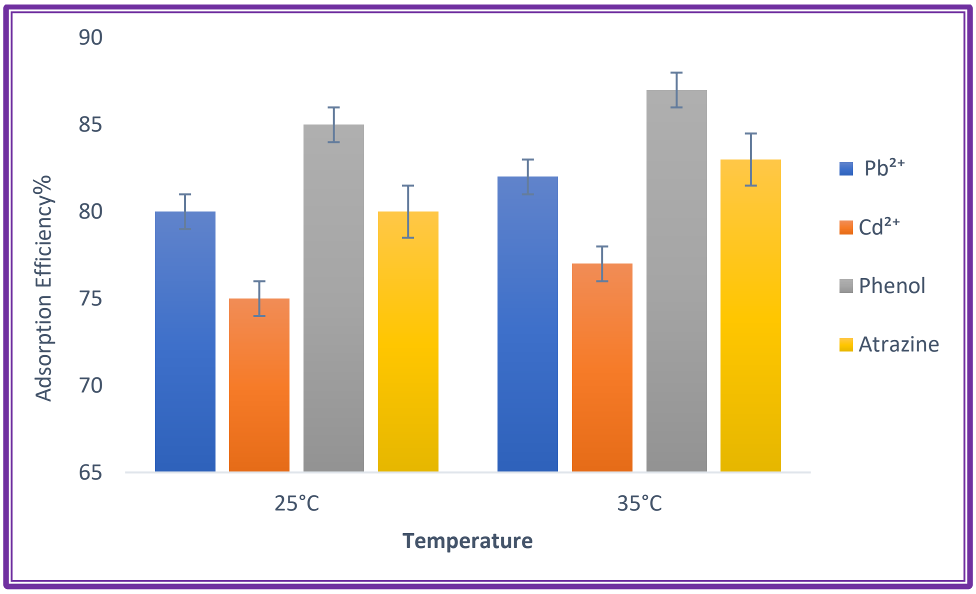

Figure 3: *The effect of temperatures on the absorption performance of acid-treated rice husk*

The percentage adsorption efficiency of the four different adsorbents—acid-treated rice husk, activated carbon, chitosan, and bentonite clay—in the removal of Lead², Cadmium², Phenol, and Atrazine is depicted in Figure 4. With adsorption rates of about 75% and 60%, chitosan and bentonite clay left low residual adsorption, whereas acid and activated carbon-treated rice husk left exceptional adsorption of about 90% to 85% of Pb2+. Somewhat lower than that of Pb^{2+}, the efficiency for Cd^{2+} was quite good for the top group members, acid-treated rice husk, and activated carbon, which were at 85% and 80%, respectively. Chitosan and bentonite clay are at the very low end with approximately 65% and 55%, while again acid-treated rice husk and activated carbon are the best adsorption efficiency near 90% concerning phenol. Atrazine was better adsorbed by ACA-treated rice hulls to about 80%, while chitosan and bentonite clay had lower adsorption efficiencies—about 70% and 50%, respectively—for chitosan and bentonite clay. Generally, from these results, acid-treated rice husk, and activated carbon are noted to be more efficient in adsorption over a wide range of Pb2+ and phenol because they possess relatively larger surface areas and possess more affinity toward these specific pollutants.

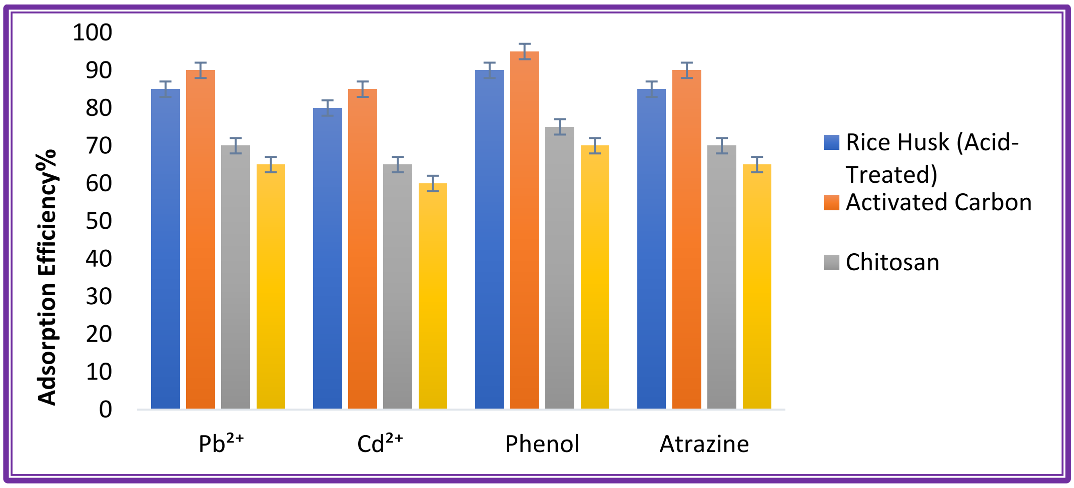

Figure 4: *Percentage adsorption efficiency of acid-treated rice husk, activated carbon, chitosan, and bentonite clay*

The whole surface area was examined by using FTIR and BET techniques to solve the adsorption process, and experiments were conducted on how this occurs. Figures 5 shows FTIR spectra of rice straw before and after acid treatments. The red and black spectra in the image represent test 1 and test 2, respectively. Transmittance (%T) is recorded for different wavelengths (cm^{-1}) and functional groups are related to specific vibrations. The major functional group detected is probably the O-H stretching due to a hydroxyl group. This occurs as a large peak at 3279.46 cm^{-1} in the red spectrum. C-H stretching present on aliphatic molecules forms a very intense band between 2923.14 cm^{-1} and 2853.21 cm^{-1}. One possible assignment for the band at 1744.72 cm^{-1} corresponds to the stretching vibration of C=O functionality commonly found in many carbonyl groups in molecules. Besides, it can be deduced that the readings at 1639.52 cm^{-1} and 1150 cm^{-1} are associated with C=C and C-O vibrational modes, respectively.

The pollutants including Pb^{2+}, Cd^{2+}, phenol, with atrazine can be removed via reverse osmosis, activated carbon, acid-treated rice husk, and coagulation flocculation. Figure 6 shows the varying effectiveness of adsorption for various methods. The most effective removal method is reverse osmosis (RO) (95% for lead², 90% for chlorine², 98% for phenol, and 95% for atrazine). This is due to its ability to filter at the molecular level, successfully removing organic and inorganic contaminants. RO membranes excel in removing small dissolved particles such as heavy metals together with organic molecules due to their small pore size and high specificity (Al-Amoudi & Lovitt, 2007).

Discussion

The findings presented indicate better adsorptive capacity of acid-treated rice husk (RH), compared to untreated husk, for removal of heavy metals (Pb^{2+}, Cd^{2+}) and organic pollutants (phenols, atrazine) in aqueous media (Figure 1). Observed increased efficiency in adsorption can be attributed to larger surface area and presence of hydroxyl and carboxyl functional groups introduced by acid treatment, which enhance adsorption from interaction with pollutants (Li *et al.,* 2020; Jain *et al*., 2022). The effect of pH on the adsorption process is indeed strong (Figure 2). Maximum removal efficiencies were found to be slightly acidic to neutral (pH ~ 6.5), corroborating previous results. Characteristics of the surface charge of the rice husk under this pH favor strong binding with cationic and anionic contaminants (Mekonnen *et al.,* 2016; Ali *et al.,* 2013). Similar pH effect for organic pollutants being adsorbed on rice husk was also observed by Hu *et al.,* 2022. Temperature also plays a role in the efficiency of adsorption (Figure 3). There is a slight increase in the adsorption of Pb^{2+} and phenol at higher temperatures, implying that higher temperatures promote a greater interaction of these pollutants with the adsorbent surface. The negligible temperature effect on Cd^{2}+ adsorption suggests a different interaction mechanism. The slight decrease in atrazine adsorption at higher temperature could indicate some degree of instability of adsorbent-atrazine complex at increased temperatures (Yadav, Sharma and Verma 2023). Adsorption efficiencies with respect to the various adsorbents (acid treated rice husk, activated carbon, chitosan, bentonite clay) indicate that acid treated rice husk and activated carbon have excellent performance (Figure 4). Chitosan and bentonite clay have lower adsorption rates. However, the results show that acid-treated rice husk performed comparably to activated carbon for the removal of phenol and Pb^{2}+. Enhanced adsorptive ability of acid-treated rice husk has been confirmed using FTIR analysis through the presence of important functional groups on the adsorbent surface (Figure 5). O-H stretching at 3279.46 cm-1, C-H stretching between 2923.14 cm-1 and 2853.21 cm-1, C=O stretching at 1744.72 cm-1, and C=C/C-O vibrations at 1639.52 cm-1 and 1150 cm-1, respectively, indicate the presence of hydroxyl, aliphatic, carbonyl, and alkene/ether functionalities. They will significantly contribute to the adsorption process by providing active sites for pollutant binding. Compared to other water purification technologies, such as reverse osmosis (RO) and coagulation-flocculation, acid-treated rice husk provides a realistic and low-cost alternative (Figure 6). RO removes all other pollutants with greater efficiency because it filters at molecular level (Al-Amoudi & Lovitt 2007). On the other hand, while activated carbon is high on adsorption capacity, it is more affordable and biodegradable, especially for treatment of industrial effluents. Coagulation-flocculation does not remove dissolved pollutants very well, but might potentially serve as a preparatory step (Verma, Dash & Bhunia 2012). The entire study upholds acid-treated rice husk as a promising, low-cost, sustainable adsorbent for heavy metals and organic pollutants from aqueous solutions. Research should focus on optimizing the acid treatment process and on field performance studies with rice husk ones in the near future.

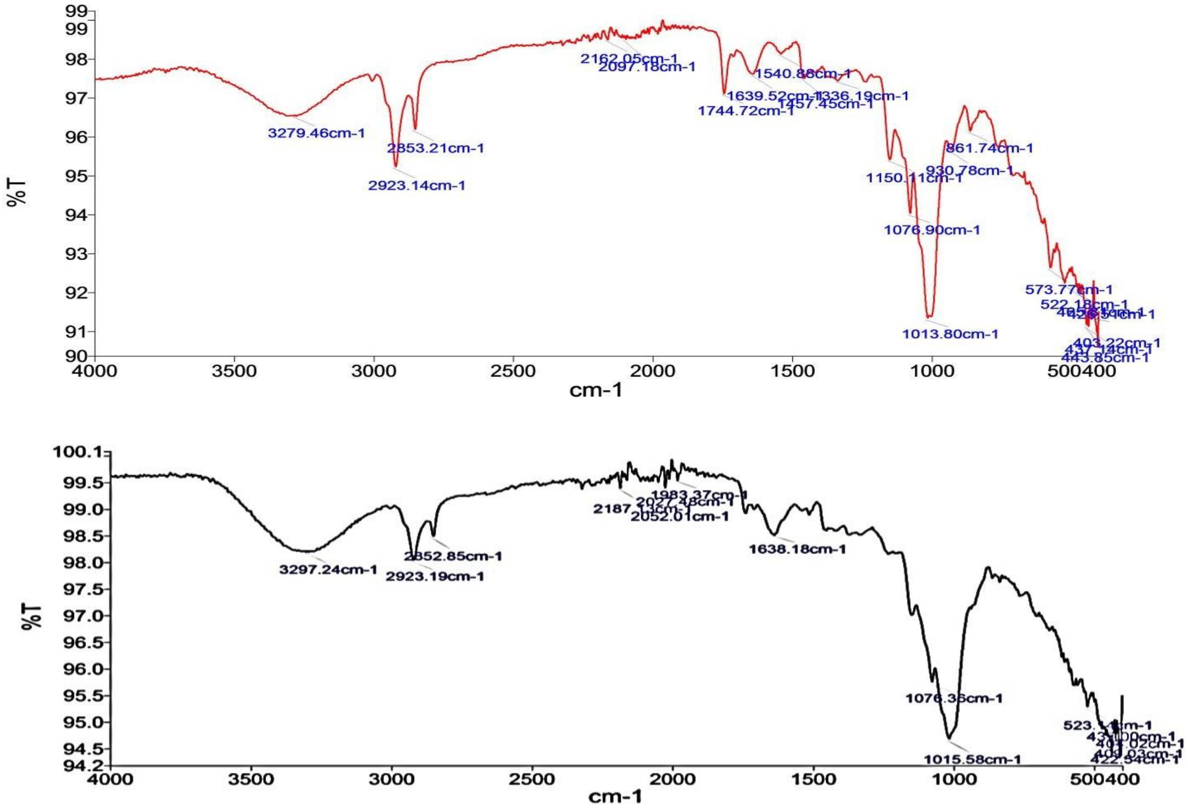

Figure 5: *Shows untreated and acid-treated rice husk. FTIR Spectra*

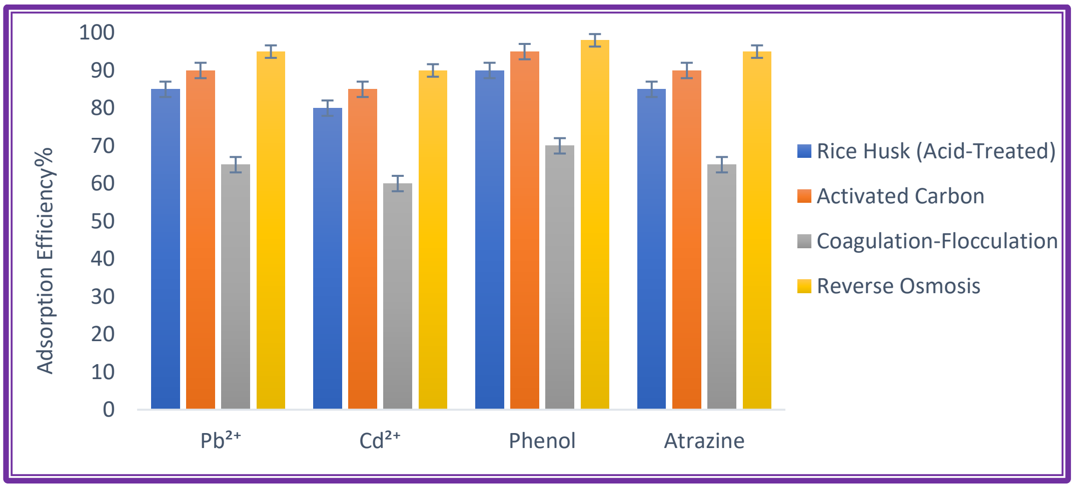

Figure 6: *Evaluation of Water Purification Techniques for the Treatment of Industrial Effluent*

Conclusion

Pre-treatment significantly enhances the sorption activity of adsorbents: Thus, the acid-treated rice husk is also better than many other adsorbents for the uptake of shrimp^{2+} and phenol, suggesting it as a promising, cost-effective, and environmentally friendly alternative to expensive treatments such as using activated carbon. While there are hi-tech, high efficiency technologies like activated carbon and reverse osmosis in the industry, the husk of rice still stands as a good contender place to an economically viable solution while treating water in the best economic and eco-friendly way. Sorption of atrazine and phenol, as well as the heavy metals Pb^{2+} and Cd^{2+} onto acid-modified rice husk, is mostly affected by pH and temperature. Rice husk removes around 85% of phenol and about 90% of lead at a pH of around 6.5. Though temperature differences did not bring statistically significant results, some modest increase in adsorption efficiency at 35°C was observed for some contaminants, like Pb^{2+} and phenol.

Conflict of Interest

The authors declare that they have no competing interests.

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