EUROPEAN JOURNAL OF MATERIALS SCIENCE AND ENGINEERING
Volume 8, Issue 3, 2023: 115-127 | www.ejmse.ro | ISSN: 2537-4338

EJMSE

DOI: 10.36868/ejmse.2023.08.03.115

APPLICATION OF RICE HUSK WASTER IN WATER REMEDIATION IN VIETNAM: A REVIEW

Dam Thi Minh TAM[1], Bui Phuong LINH[1*]

[1]Faculty of Environment, Ho Chi Minh City University of Natural Resource and Environment, 236B Le Van Sy Str., Tan Binh Dist., 721000 Ho Chi Minh City, Vietnam

Abstract

Rice husk is a byproduct of rice milling that is commonly available in Vietnam due to the country's massive rice producing industry. While rice husk has traditionally been considered a waste product, recent research has shown that it has potential for use in wastewater treatment. This study comprehensively reviews a multitude of aspects regarding the application of rice husk waste in water treatment in Vietnam. The effectiveness of rice husk as an adsorbent material for removing heavy metals, organic compounds, and dyes from wastewater is highlighted. Besides, rice husk is even used for treating floodwater in Vietnam. The use of rice husk waste for water treatment has significant potential for both environmental and economic benefits for Vietnam. It provides a low-cost, sustainable alternative to traditional wastewater treatment methods and can help to address the country's ongoing water pollution challenges.

Keywords: *rice husk; water remediation; adsorptive removal; activated carbon.*

Introduction

Rice husk is a byproduct of the rice milling process and is considered a waste product in agricultural countries where rice cultivation occupies the largest proportion of the crops produced, including in Vietnam [1]. According to the Ministry of Agriculture and Rural Development's projections, Vietnam's yearly rice husk production will be around 8.8 million tons. The Fig. is projected to rise in the coming years due to the country's growing rice industry. As a result, rice husk waste creates a number of environmental issues in Vietnam, especially in terms of disposal and management. Air and water pollution, waste management challenges, and greenhouse gas emissions are some of the key environmental problems associated with rice husk waste in Vietnam. The open burning of rice husk waste is typical in many parts of Vietnam, particularly in rural areas. These fires emit a lot of smoke, particulate matter, and greenhouse gases into the atmosphere, which contributes to air pollution and climate change. [2]. These emissions can have detrimental effects on air quality, human health, and the environment. Besides that, improper disposal of rice husk waste can lead to water pollution. When rice husk waste is discarded in water bodies such as rivers or lakes, it can degrade water quality by releasing organic matter and nutrients, leading to eutrophication [3]. Eutrophication can cause excessive algae growth, oxygen depletion, and harm aquatic ecosystems. Noticeably, the sheer volume of rice husk waste generated by Vietnam's rice production industry presents significant waste management challenges. Inadequate infrastructure and lack of proper waste management systems can result in the accumulation of rice husk waste, leading to land pollution and hindering land use [4]. Finally, when rice husk waste decomposes in landfills or stagnant water bodies, it produces methane gas, which is a potent greenhouse gas with a significant impact on climate change [5]. Methane

*Corresponding author: hoanghieny@duytan.edu.vn

emissions from rice husk waste contribute to the country's overall greenhouse gas emissions and global warming potential [6]. Addressing these environmental problems associated with rice husk waste in Vietnam requires implementing sustainable waste management practices. The development of efficient technologies and waste management systems can help minimize the negative environmental impacts of rice husk waste, reduce air and water pollution, and mitigate climate change effects. In recent years, researchers and entrepreneurs in Vietnam have begun to explore the potential uses of rice husk waste. Besides application in energy generation, building materials, animal feed, and soil amendment, rice husk is mainly used in water treatment in Vietnam. One of the main applications of rice husk in water treatment is as a raw material for adsorbent production. Rice husk contains high levels of silica, which can be activated to create a porous structure capable of adsorbing contaminants from aqueous solution [7]. This makes rice husk a potent substitute for conventional adsorbent substances like activated carbon. According to studies conducted in Vietnam, rice husk has a high adsorption capacity and is less expensive than conventional adsorbent materials. It is even employed in the supply water treatment system. One of the advantages of using rice husk waste for wastewater treatment in Vietnam is its low cost and availability. It is also very sustainable to use rice husk for wastewater treatment. The use of rice husk in wastewater treatment lessens the environmental impact of the rice producing industry and aids in addressing the issue of water pollution in Vietnam by reusing a material that would otherwise be discarded. Additionally, the use of rice husk for wastewater treatment reduces the need for expensive and energy-intensive treatment processes, making it a cost-effective solution for wastewater treatment in Vietnam. One of the challenges of using rice husk as an adsorbent material is its variability in composition and properties, which can affect its effectiveness in water treatment. However, researchers in Vietnam have been working on developing methods to optimize the activation of rice husk and improve its effectiveness as an adsorbent material for water treatment. To gain a comprehensive understanding and obtain detailed information on the specific studies and advancements in using rice husk waste for water treatment in Vietnam, herein, we investigate the recent application of this waste in water treatment in Vietnam. The review mainly focuses on the following four aspects: 1- the situation of rice husk emission in Vietnam; 2 – the advantages of using rice husk as a material for water remediation; 3 – the application of rice husk waster in wastewater treatment; 4 – the application of rice husk waster in supply water treatment system.

The article presents a description of the technology for the production of magnetic composites at low compression pressures based on amorphous iron alloys using a polymer resin as a matrix.

Situation of rice husk emission in Vietnam

Vietnam is one of the world's largest rice growers, and as a result, it generates a huge amount of rice husk trash. Vietnam's rice husk emission is inextricably linked to the country's rice farming industry. According to the Vietnamese Ministry of Finance, one of the goals for the country's rice export market in the 2017-2020 timeframe, with a long-term goal of 2030, was to gradually reduce rice export volume while raising export rice value. In particular, the annual rice export volume was predicted to reach approximately 4.5 - 5 million tonnes in 2020, earning an estimated USD 2.2 - 2.3 billion per year. The country's annual rice export volume is expected to be around 4 million tonnes between 2021 and 2030, earning USD 2.3 - 2.5 billion per year. Simultaneously, it would restructure rice export products. Exports of aromatic rice, specialty rice, and Japonica rice will account for 40 percent of total exported rice volume, followed by glutinous rice and white rice exports at 25 percent each. In Vietnam, rice is also referred to as “white gold”. Rice production is critical to Vietnam’s agricultural industry, constituting 30% of the country’s total agricultural production value. Rice farming takes up about half of all agricultural land [8]. The overall harvested area of paddy fields is about 7.7 million hectares, with the Mekong River

Delta and Red River Delta regions having the highest amounts of harvested areas. The Mekong Delta alone is home to 20% of Vietnam's population and produces more than 50% of Vietnam's rice output and exports more than 90% of its rice [9]. As seen in Fig. 1, the Mekong River Delta produces 54 percent of Vietnam's rice and the Red River Delta produces 17 percent [8, 10].

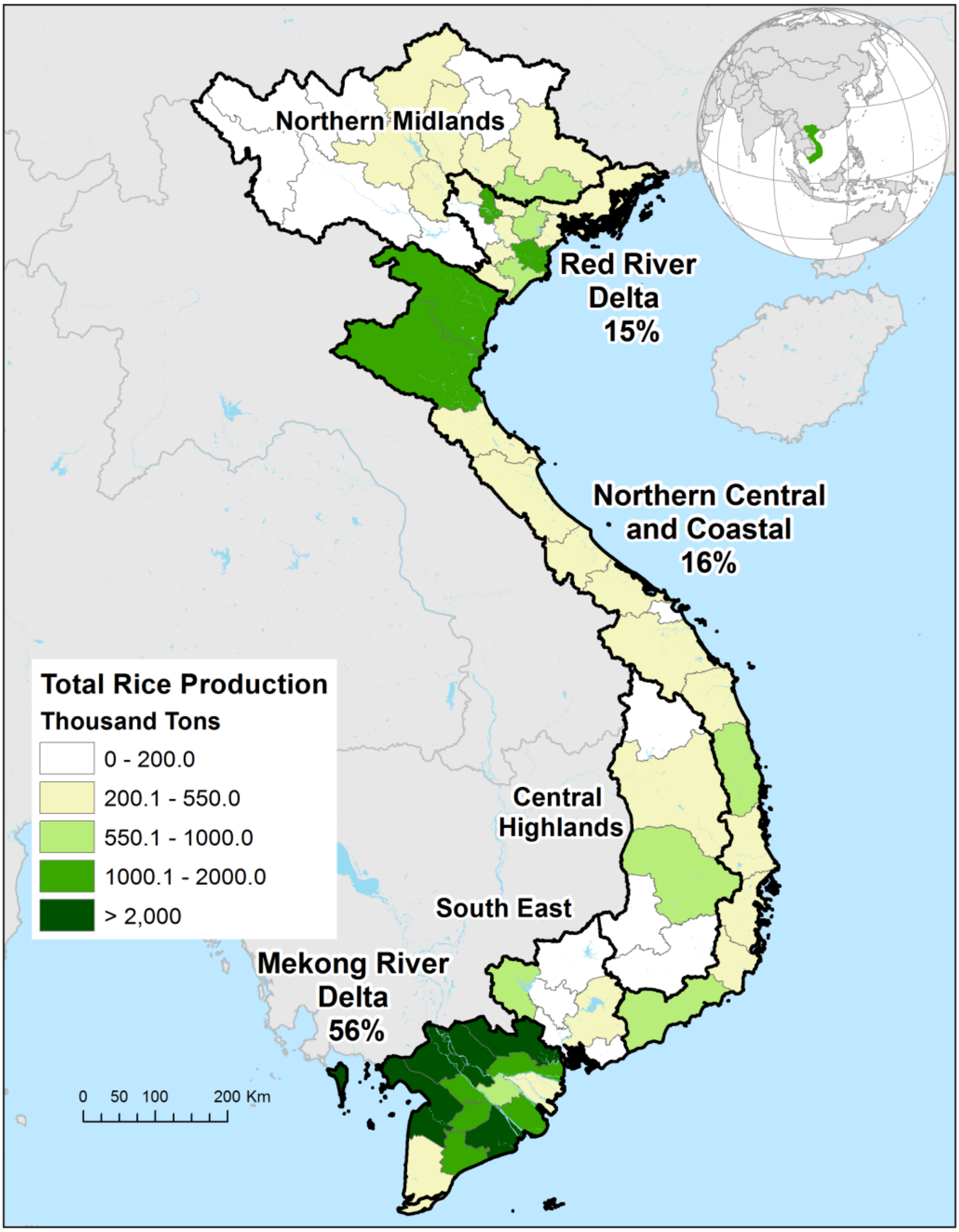

Fig. 1. Distribution area of rice cultivation in Vietnam [8, 10]

The large rice production industry in Vietnam generates a significant amount of rice husk waste, which has traditionally been considered a nuisance and often burned, contributing to air pollution and greenhouse gas emissions. The rice husk is the outer layer or husk that surrounds the rice grain [11]. The husk is separated from the rice grain during the milling process, resulting in rice husk waste. This is a cellulose-based fiber that accounts for around 20% of the weight of rice. Table 1 shows the composition of rice husk generated from a local rice mill in An Giang province, Vietnam. As a result, its composition is as follows: cellulose (45-50%), lignin (27-33%), silica (10%-15%), and moisture (10%-15%). Rice husks under observation display a light yellow coloration, characterized by an oval shape with an average long of 9 mm, width of 2.25 mm, and thickness of about 0.13 mm (Fig. 2).

Table 1. The elemental component and dimension of the rice husk.

Elemental component, %		Dimension, mm	
C	38.92	Long	8 - 10
H	4.90		
N	2.24	Wide	2.0 - 2.5
O	27.12		
Humility	11.5	Thick	0.1 - 0.15
Ash	12		

Fig. 2. Rice husk image

It is estimated that Vietnam produces approximately 8.8 million tons of rice husk waste annually. The Fig. is expected to increase in the coming years due to the growth of the rice industry in the country. According to the Ministry of Agriculture and Rural Development's plan, the husks will increase to 9.21 tonnes by 2025. Rice husk itself does not cause pollution. However, improper management and disposal of rice husk waste can lead to pollution and environmental concerns. Historically, deemed as a kind of waste, rice husks were dumped into rivers or burned in fields, wasting a remarkable source of energy while badly affecting the environment, particularly in rural areas where proper waste management infrastructure is limited. When rice husk is burned in open fields or makeshift burn piles, it releases smoke, particulate matter, and various gases into the atmosphere. These emissions contribute to air pollution and can have detrimental effects on air quality, human health, and the environment. The smoke and particulate matter released during rice husk burning contain pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), volatile organic compounds (VOCs), and fine particulate matter (PM2.5) [12]. These pollutants can cause respiratory problems, eye irritation, cardiovascular issues, and other health complications when inhaled. Moreover, the greenhouse gases released during rice husk burning, including carbon dioxide (CO_2) and methane (CH_4), contribute to climate change [13]. Methane, in particular, is a potent greenhouse gas with a higher global warming potential than carbon dioxide in the short term. The decomposition of rice husk waste in landfills or stagnant water bodies can also result in methane emissions.

Improper disposal of rice husk waste can lead to water pollution. When rice husk waste is discarded in water bodies such as rivers or lakes, it can degrade water quality by releasing organic matter and nutrients. This can cause eutrophication, which is an excessive growth of algae that depletes oxygen levels in water bodies. Eutrophication can harm aquatic ecosystems, leading to fish kills and imbalances in the aquatic environment [14].

If rice husk waste is not properly disposed of, it may build up in the ground and cause soil pollution. This might happen if discarded rice husk is thrown on land or utilized as fill material without taking the proper precautions. Waste rice husks can potentially pollute the soil with heavy metals or other contaminants, change nutrient balances, and impact soil fertility [15].

Therefore, adequate waste management techniques should be used to reduce pollution caused by rice husk trash. The innovative and environmentally friendly method of treating water using rice husk has gained popularity recently. Research and pilot projects have been carried out to investigate the use of rice husks for water purification in Vietnam and other nations. These initiatives seek to combat water pollution and offer affordable water treatment options by maximizing the potential of this abundant and renewable material.

Advantages of using rice husk as a material for water remediation

Firstly, rice husk contains high levels of silica and has a porous structure, making it an excellent adsorbent material [16, 17]. The porous nature of rice husk provides a large surface area for adsorption, allowing it to effectively capture and remove pollutants from aqueous solution [18, 19].

Secondly, the inexpensive cost of employing rice husk for water remediation is one of its advantages. Rice husk is a byproduct of the rice business that is commonly available and affordable in comparison to other adsorbent materials. This makes it an appealing choice, particularly in areas where financial resources for wastewater treatment are limited [20]. The price of rice husks in Vietnam can vary depending on various factors such as location, demand, supply, and market conditions. Averagely, the price per ton of rice husks fluctuates around $25 in Vietnam.

Finally, utilizing rice husk for wastewater treatment aligns with sustainability principles. Repurposing a waste product reduces environmental impacts associated with rice husk disposal and contributes to a circular economy approach. Additionally, the use of rice husk for water treatment can help address water pollution issues and promote sustainable water management practices.

Application of rice husk waster in wastewater treatment

Pollutants such as metals and organic chemicals can be found in wastewater. Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), chromium (Cr), and copper (Cu) can be found in industrial wastewater from mining, metal plating, electronics, and manufacturing operations [21]. These metals are toxic and can have detrimental effects on human health and the environment. Other trace metals like zinc (Zn), nickel (Ni), manganese (Mn), and iron (Fe) may also be found in wastewater. While these metals are required in trace amounts for biological processes, excessive concentrations can be harmful. Talking about the organic pollutants in wastewater, it is necessary to refer to pharmaceuticals, pesticides, herbicides, polycyclic aromatic hydrocarbons, and volatile organic compounds (VOCs) [22]. In Vietnam, rice husk can be effectively utilized as a precursor of adsorbent material for removing these pollutants. The most basic form of adsorbent from rice husk is activated carbon (AC) and biochar [23, 24]. The process of production of AC derived from rice husk has consisted of the following stages:

Collection and Preparation: Rice husk waste is collected from rice mills or agricultural sources. It is then cleaned and dried to remove any impurities or moisture content.

Carbonization: The dried rice husk is subjected to a carbonization process. Carbonization involves heating the rice husk in the absence of oxygen at high temperatures (typically between 500 to 800 degrees Celsius). This process converts the organic components of the rice husk into carbon, leaving behind ash and volatile components.

Activation: There are two common methods for activating rice husk: physical activation and chemical activation.

- Physical Activation: In physical activation, the carbonized rice husk is further heated in the presence of an activating agent, usually steam or carbon dioxide. This process creates a porous structure by gasifying the remaining volatile components, resulting in the development of pore structures within the carbon.

- Chemical Activation: In chemical activation, the carbonized rice husk is impregnated with a chemical activating agent, such as potassium hydroxide (KOH) [23], potassium carbonate (K_2CO_3) [24], and phosphoric acid (H_3PO_4). The impregnated rice husk is then heated at moderate temperatures to activate the carbon and create porosity. Fig. 3 shows micrographs of materials formed following carbonization (a) and activation (b) of rice husk. The porosity of the material expanded considerably when it was activated, as can be shown.

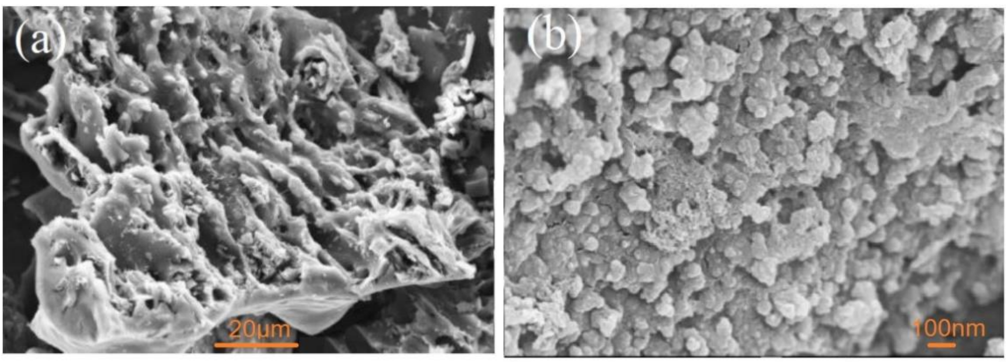

Fig. 3. Micrographs of materials obtained after carbonization (a) and activation (b) of rice husk [25]

Washing and Drying: After the activation process, the activated carbon is washed thoroughly to remove any residual impurities or activating agents. This is followed by drying to remove moisture content.

Unlike the production process of AC, biochar from rice husk is prepared by pyrolysis at 450-600°C [26, 27].

The obtained materials are highly porous material with a large surface area. Mai T.T. and co-workers successfully synthesized activated carbon from rice husk by carbonizing the rice husk and activating the chemical by K_2CO_3. The resulting AC has a large surface area of 1583 m^2g^{-1} and a pore volume of 0.93 $cm^2.g^{-1}$ [24]. Meanwhile, the surface area of biochar from rice husk is lower than that of AC (360-380 m^2 g^{-1}) [26]. Surprisingly, these materials contained hollow tunnels, which may be attributed to adsorption (Fig. 4).

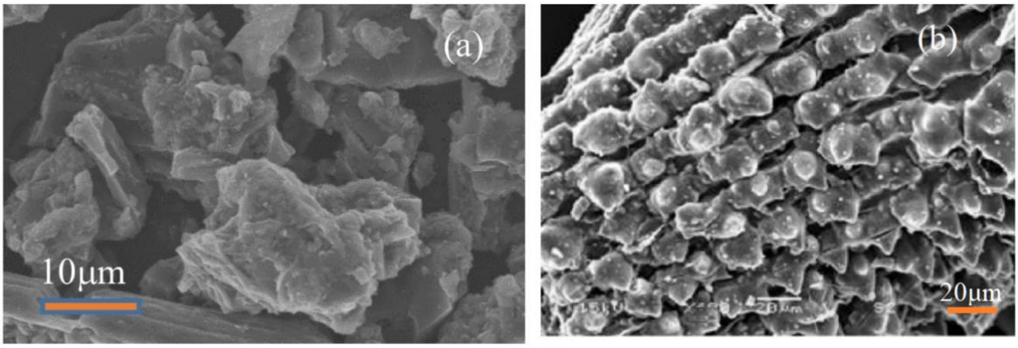

Fig. 4. SEM images of AC (a) and biochar (b) derived from rice husk [24], [26]

The prepared AC and biochar were then used to adsorb the pollutants such as industrial dyes, heavy metals, and others. Tan T.V. and co-workers used AC from rice husk waste, which was activated by KOH, for the adsorptive removal of methylene blue (MB). The obtained result showed that the MB adsorption efficiency reached over 80 % at a concentration of 50 mg/L, pH 8 within 180 minutes [24]. The biochar from rice husk is also highly efficient adsorbent material for MB removal. However, the obtained biochar was activated by chemicals to improve the dye removal efficiency. Bui H.T. and co-workers activated biochar from rice husk using NaOH 25% in order to enhance the MB adsorption efficiency. Accordingly, the biochar activated by NaOH for 4 hours at room temperature was optimal, and the MB removal effectiveness immediately approached 100% after the first hour of adsorption [26].

Recently, researchers in Vietnam have been working on developing methods to optimize the activation of rice husk and improve its effectiveness as an efficient adsorbent material for water treatment. Activated rice husk ash functionalized with metal and organic compounds is preferred to be used to increase the efficiency of water treatment. Activated rice husks-supported metal compounds such as silver nanoparticles, magnesium oxide, and iron oxyhydroxide were successfully prepared for adsorptive removal of chloride [28], ammonia [29] and arsenic [30]. In particular, coating activated rice husk with iron oxyhydroxide (FeOOH) can increase the removal capacity for As(V) from aqueous solutions [30]. Adsorption is mostly determined by the number of iron sites on the adsorbent's surface. Iron used to modify adsorbents can be of numerous forms, including amorphous iron oxide, ferrihydrite, aragonite, goethite, hematite, and others, depending on circumstances such as pH and temperature. At pH 4, the prepared rice husk-FeOOH material has a 99.6 percent As(V) removal capability [30]. Nguyen T.T. and co-workers designed and fabricated activated rice husk ash-supported silver nanoparticles for chloride removal [28]. The rice husk ash was collected from a furnace for brick production in An Giang province. TEM images of activated rice husk ash–supported silver nanoparticles 5% and 10% are presented in Fig. 5a. The effects of adsorption time on the chloride adsorption in the presence of activated rice husk ash (ARHA), and activated rice husk ash–supported silver (Ag/ARHA) are illustrated in Fig. 5b. Interestingly, While ARHA did not exhibit chloride adsorption, the chloride capacity of the 5 percent Ag/ARHA adsorbent reached 7.9 mg Cl^-/gAg. The surface area of 5 percent Ag/ARHA is less than that of ARHA, indicating that Ag nanoparticles are the primary adsorption sites for chloride adsorption while ARHA material serves as a carrier or supporting material.

In addition to metal compounds, ARHA was also functionalized with amine to form an effective adsorbent for the simultaneous removal of organics and anions in wastewater [31]. Because of the strong activity of amine groups and the uniform dispersion of amines on the ARHA surface, the amine-grafted on the ARHA carrier (amine-ARHA) provides exceptional pollutants adsorption capability.

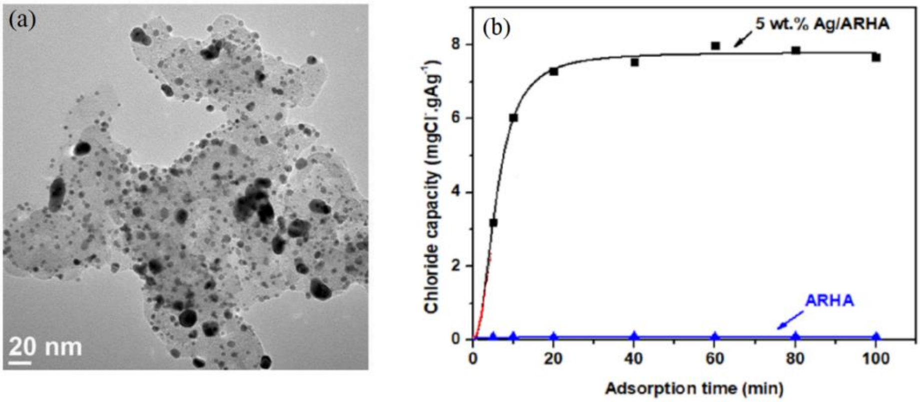

Fig. 5. TEM image of 5%Ag/ARHA(a) and effects of adsorption time on chloride adsorption in the presence of ARHA and 5%Ag/ARHA [28]

Fig. 6 depicts the hypothesized adsorption mechanism of amine-ARHA against contaminants such as nitrate (NO^{3-}), phosphate (PO_4^{3-}), and methyl orange (MO). Accordingly, A conjugated adsorption mechanism may occur on the surface of the amine-ARHA adsorbent, which can be attributed to the amine groups in the MO molecule being further activated by H+ (released from the surface amine groups) or Na+ ions (present in the solution) to form new adsorption centers for nitrate and phosphate. The amine-ARHA material proved more advantageous for multipollutant removal than other materials in the treatment of real wastewater due to its conjugated adsorption process [31].

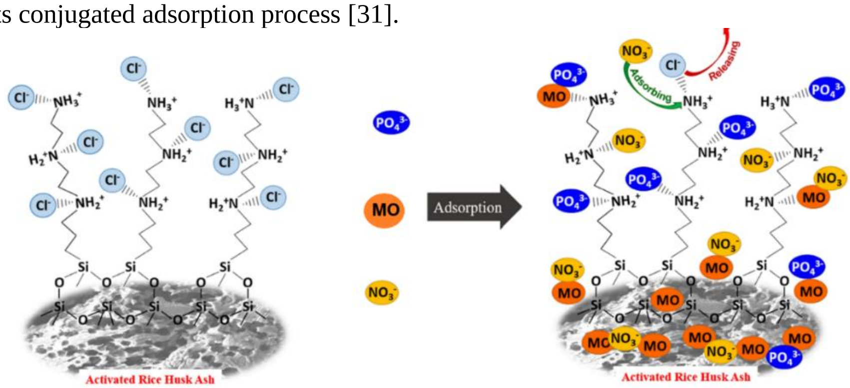

Fig. 6. Proposed conjugate adsorption mechanism of the amine-ARHA adsorbent [31]

Overall, the application of rice husk waste in wastewater treatment in Vietnam has emerged as a promising and sustainable solution to address water pollution challenges. However, further research and optimization of the activation processes are needed to enhance the efficiency and performance of rice husk as an adsorbent material.

Application of rice husk waster in the supply water treatment system

The application of rice husk waste in the supply water treatment system is a promising and innovative approach to improve water quality and ensure safe drinking water. Similar to the process of wastewater treatment, rice husk ash (RHA) is also used as an effective adsorbent in the supply water treatment system.

Tran N.T. and co-workers have proposed to treat fluoride 45 water wells used for drinking at three communes in Ninhhoa district, Khanhhoa province of Vietnam, using adsorbent based aluminum hydroxide coated rice husk ash [32]. RHA in this project was collected from the Hue province of Vietnam. RHA particles were porous, homogeneous, and had a mean size of about 100 nm. Surprisingly, the creation of capillary networks was caused by the assembly of RHA particles. However, because $Al(OH)_3$ was coated over RHA, it partially occluded the capillary networks, lowering RHA/$Al(OH)_3$ surface area. Fig. 6 shows a TEM image of the morphology of RHA/$Al(OH)_3$.

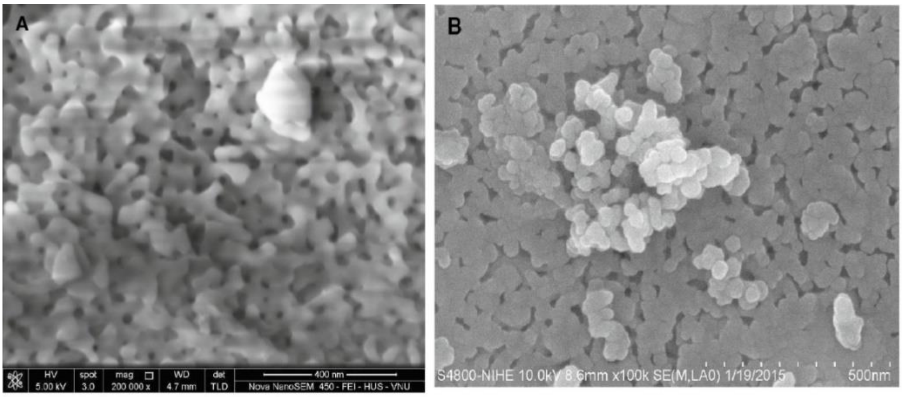

Fig. 7. SEM images of RHA (a) and RHA/$Al(OH)_3$ (b) [32]

In this experiment, the authors collected ten well-water samples at the Ninhthuong commune for practical purposes. Fluoride concentrations in the samples ranged from 8.4 to 10.1 mg L^{-1}. The appropriate RHA/$Al(OH)_3$ dose ranged from 1 g L^{-1} to 10 g L^{-1}. To achieve adsorption equilibrium, the mixtures were agitated for 2 hours. Table 2 displays the acquired results. The results revealed that increasing the dose of RHA/$Al(OH)_3$ from 4.0 g L-1 to 7.0 g L^{-1} reduces the remaining fluoride concentration below the WHO recommended range (0.5-1.5 mg L^{-1}).

Table 1. The elemental component and dimension of the rice husk [32].

Samples	Dose of the adsorbent (g L^{-1})	Fluoride concentration (mg L^{-1})	Removal efficiency (%)
1	1	3.48	65.5
2	2	2.40	76.2
3	3	1.72	83.0
4	4	1.13	88.8
5	5	0.76	92.5
6	6	0.63	93.8
7	7	0.57	94.4
8	8	0.49	95.1
9	9	0.45	95.5
10	10	0.31	96.9

Researchers in Vietnam have explored the use of rice husk-based media in filtration systems. By processing rice husk into AC, it can be employed in slow sand filtration or packed bed filters to remove impurities, including suspended solids, organic matter, and certain contaminants, resulting in improved water quality. Recently, Dao M.U. and co-workers have successfully treated the floodwater in the Vietnamese Mekong Delta using a simple filter system based on silver nanoparticles coated onto AC derived from rice husk (AgNPs@AC) [33]. The overall scheme of floodwater treatment using AgNPs@AC was described in Fig. 8.

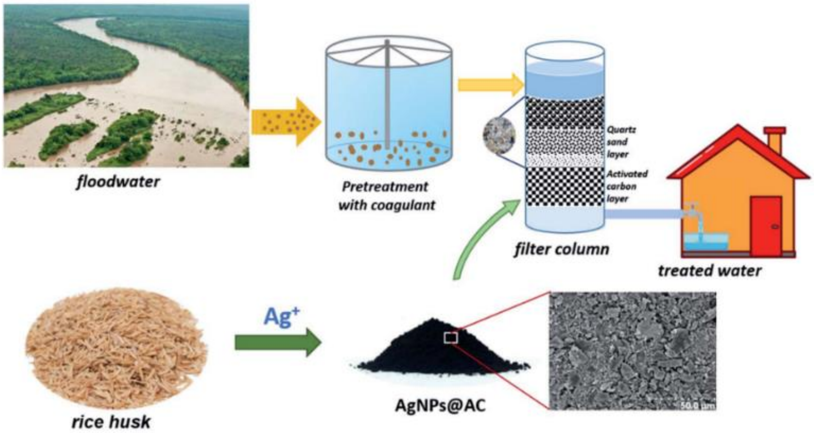

Fig. 8. Overall scheme of floodwater treatment using AgNPs@AC [33]

In particular, the initial water supply received from the Hau Giang River would be pre-treated by the coagulation process before being dumped into the filtration column to remove suspended materials. The pre-treated floodwater was then routed from top to bottom via a filter column. To remove untreated suspended particulates while simultaneously lowering the vortex speed of the water flowing through the AC layer, a thin coating of quartz sand was added on top of the AgNPs@AC layer. It has been proved that floodwater treated by the suggested filter system can be used totally to meet basic human needs. Furthermore, with a processing capacity of 20 liters per day, the filter column composed of a 10 mm thick AgNPs@AC layer could process continuously (Fig. 9).

Even more importantly, the treatment of one cubic meter of floodwater using silver nanoparticles coated onto activated carbon derived from rice husk will only cost nearly 0.17$ [33].

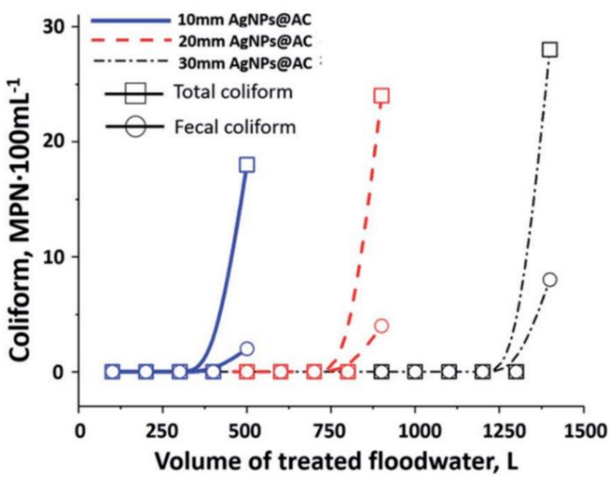

Fig. 9. The treatment capacity of the filter column based on AgNPs@AC [33]

This project's findings not only improved our understanding of activated carbon-coated nanoparticles' floodwater treatment capacity, but they also supplied useful information for water treatment plants along the Hau Giang River, aquatic ecosystem researchers, and public health researchers.

Conclusions

Overall, rice husk is no longer agricultural waste in Vietnam, it has become a useful raw material for manufacturing wastewater treatment materials, most typically activated carbon, and biochar. These naturally sourced materials have been utilized as effective adsorbents to treat a wide range of contaminants such as heavy metals, industrial dyes, and organic pollutants. Moreover, these adsorbents have been practically employed for flood and drinking water treatment purposes.

Numerous attempts have been successful to improve the treatment efficacy of these adsorbents, such as the immobilization of metals and their compounds into the carbon matrix, thereby increasing the applicability of the husk-based carbon materials in water remediation. the utilization of rice husk waste contributes to reducing the reliance on conventional water treatment methods that may involve the use of chemicals or energy-intensive processes.

This review is confined to the application of rice husk waster for water remediation specifically within the context of Vietnam. Therefore, a comprehensive review of the global application of “green” material is essential to better understand its potential in safeguarding the aquatic environment.

References

[1] N. Van Song *et al.*, *Development of Rice Husk Power Plants Based on Clean Development Mechanism: A Case Study in Mekong River Delta, Vietnam*, **Sustainability**, **13(12)**, 2021, p. 6950. DOI: 10.3390/su13126950.

[2] P.-T. H. Phuong, T.-D. Nghiem, P.-T. M. Thao, C.-T. Pham, T.-T. Thi, and N. Thanh Dien, *Impact of rice straw open burning on local air quality in the Mekong Delta of Vietnam*, **Atmos. Pollut. Res.**, **12(11)**, 2021, p. 101225. DOI: 10.1016/j.apr.2021.101225.

[3] I. J. Njoku, P. Nwaokafor, and N. K. Okeke, *Assessment of the contamination of rice husk ash of Izzi CP, Ikwo CP and Izzi R8 rice species of South-Eastern Nigeria*, **Environ. Challenges**, **5**, 2021, p. 100232. DOI: 10.1016/j.envc.2021.100232.

[4] R. Pode, *Potential applications of rice husk ash waste from rice husk biomass power plant*, **Renew. Sustain. Energy Rev.**, **53**, 2016, pp. 1468–1485. DOI: 10.1016/j.rser.2015.09.051.

[5] S. L. Lim, L. H. Lee, and T. Y. Wu, *Sustainability of using composting and vermicomposting technologies for organic solid waste biotransformation: recent overview, greenhouse gases emissions and economic analysis*, **J. Clean. Prod.**, **111**, 2016, pp. 262–278. DOI: 10.1016/j.jclepro.2015.08.083.

[6] P. T. Mai Thao, K. H. Kurisu, and K. Hanaki, *Greenhouse gas emission mitigation potential of rice husks for An Giang province, Vietnam*, **Biomass and Bioenergy**, **35(8)**, 2011, pp. 3656–3666. DOI: 10.1016/j.biombioe.2011.05.023.

[7] D. M. Gomez Mejia, D. F. Hincapie-Rojas, F. N. Jimenez-Garcia, and C. A. Alvarez Vargas, *Effect of the addition of silica obtained from rice husk on physicochemical and mechanical properties of fibercement*, **Heliyon**, **9(2)**, 2023, p. e13567.

DOI: 10.1016/j.heliyon.2023.e13567.

[8] K. Maitah, L. Smutka, J. Sahatqija, M. Maitah, and N. Phuong Anh, *Rice as a Determinant of Vietnamese Economic Sustainability*, **Sustainability**, **12(12)**, 2020, p. 5123. DOI: 10.3390/su12125123.

[9] M. Demont and P. Rutsaert, *Restructuring the Vietnamese Rice Sector: Towards Increasing Sustainability*, **Sustainability**, **9(2)**, 2017, p. 325. DOI: 10.3390/su9020325.

[10] "https://ipad.fas.usda.gov/countrysummary/Default.aspx?id=VM&crop=Rice."

[11] R. Siddique and P. Cachim, Waste and Supplementary Cementitious Materials in Concrete. Elsevier LTd., 2018. doi: 10.1016/C2016-0-04037-8.

[12] A. Fushimi *et al.*, *Chemical characterization and oxidative potential of particles emitted from open burning of cereal straws and rice husk under flaming and smoldering conditions*, **Atmos. Environ.**, **163**, 2017, pp. 118–127. DOI: 10.1016/j.atmosenv.2017.05.037.

[13] H. A. Le, D. M. Phuong, and L. T. Linh, *Emission inventories of rice straw open burning in the Red River Delta of Vietnam: Evaluation of the potential of satellite data*, **Environ. Pollut.**, **260**, 2020, p. 113972. DOI: 10.1016/j.envpol.2020.113972.

[14] T. Liberalesso, R. Tassi, D. E. Ceconi, D. G. Allasia, and N. K. S. Arboit, *Effect of rice husk addition on the physicochemical and hydrological properties on green roof substrates under subtropical climate conditions*, **J. Clean. Prod.**, **315**, 2021, p. 128133. DOI: 10.1016/j.jclepro.2021.128133.

[15] Z. Li *et al.*, *Review on Rice Husk Biochar as an Adsorbent for Soil and Water Remediation*, **Plants**, **12(7)**, 2023, p. 1524. DOI: 10.3390/plants12071524.

[16] N. D. Suzaimi, P. S. Goh, N. A. N. N. Malek, J. W. Lim, and A. F. Ismail, *Enhancing the performance of porous rice husk silica through branched polyethyleneimine grafting for phosphate adsorption*, ***Arab. J. Chem.***, **13(8)**, 2020, pp. 6682–6695. DOI: 10.1016/j.arabjc.2020.06.023.

[17] M. M. Alam *et al.*, *The Potentiality of Rice Husk-Derived Activated Carbon: From Synthesis to Application*, **Processes**, **8(2)**, 2020, p. 203. DOI: 10.3390/pr8020203.

[18] W. Bai *et al.*, *Rice husk-based adsorbents for removing ammonia: Kinetics, thermodynamics and adsorption mechanism*, **J. Environ. Chem. Eng.**, **9(4)**, 2021, p. 105793, DOI: 10.1016/j.jece.2021.105793.

[19] R. Nandi, M. K. Jha, S. K. Guchhait, D. Sutradhar, and S. Yadav, *Impact of KOH Activation on Rice Husk Derived Porous Activated Carbon for Carbon Capture at Flue Gas alike Temperatures with High CO 2 /N 2 Selectivity*, **ACS Omega**, **8(5)**, 2023, pp. 4802–4812. DOI: 10.1021/acsomega.2c06955.

[20] M. C. Collivignarelli, S. Sorlini, C. Milanese, W. A. M. A. N. Illankoon, F. M. Caccamo, and S. Calatroni, *Rice Industry By-Products as Adsorbent Materials for Removing Fluoride and Arsenic from Drinking Water—A Review*, **Appl. Sci.**, **12(6)**, 2022, p. 3166. DOI: 10.3390/app12063166.

[21] N. A. A. Qasem, R. H. Mohammed, and D. U. Lawal, *Author Correction: Removal of heavy metal ions from wastewater: a comprehensive and critical review*, **npj Clean Water**, **4(1)**, 2021, p. 52. DOI: 10.1038/s41545-021-00144-z.

[22] S. Mandal, A. Kunhikrishnan, N. S. Bolan, H. Wijesekara, and R. Naidu, *Application of Biochar Produced From Biowaste Materials for Environmental Protection and Sustainable Agriculture Production*, **Environmental Materials and Waste**, Elsevier, 2016, pp. 73–89. doi: 10.1016/B978-0-12-803837-6.00004-4.

[23] T. V Tan and H. T. T. Nguyen, *Activated Carbon based Rice Husk for Highly Efficient Adsorption of Methylene Blue: Kinetic and Isotherm*, **IOP Conf. Ser. Mater. Sci. Eng.**,

1092(1), 2021, p. 012078. DOI: 10.1088/1757-899X/1092/1/012078.

[24] M. T. Tung, V. D. Luong, P. M. Trang, L. Van Tuyen, H. T. Bich Thuy, and N.-L. Wu, *The synthesis and characterization of high purity mixed microporous/mesoporous activated carbon from rice husk*, **Vietnam J. Chem.**, **56(6)**, 2018, pp. 684–688. DOI: 10.1002/vjch.201800070.

[25] V. V. Korobochkin, N. V. Tu, and N. M. Hieu, *Production of activated carbon from rice husk Vietnam*, **IOP Conf. Ser. Earth Environ. Sci.**, **43(1)**, 2016, pp. 1–6. DOI: 10.1088/1755-1315/43/1/012066.

[26] H. T. Bui *et al.*, *Removal of methylene blue from aqueous solution by biochar derived from rice husk,* **Vietnam Journal of Earth Sciences**, **44(2)**, 2022, pp. 273–285. DOI: 10.15625/2615-9783/16998.

[27] V. Thuy and P. Linh, *Study on Treatment of high ammonium concentration in Piggery Wastewater Using Rice Husk Biochar*, **Ijmcer. Com**, **2(5)**, 2018, pp. 26–31.

[28] T. T. Nguyen, S. Padungthon, and N. H. Nguyen, *Activated rice husk ash-supported silver nanoparticles as a novel adsorbent toward chloride removal*, **Desalin. Water Treat.**, **160**, 2019, pp. 308–315. DOI: 10.5004/dwt.2019.24239.

[29] T. Nguyen Thi *et al.*, *Study on the Removal of Ammonia in Wastewater Using Adsorbent Prepared From Rice Hull With Magnesium Oxide Modification*, **Vietnam J. Sci. Technol.**, **58(3A)**, 2020, p. 113. DOI: 10.15625/2525-2518/58/3a/14322.

[30] E. Pehlivan, T. H. Tran, W. K. I. Ouédraogo, C. Schmidt, D. Zachmann, and M. Bahadir, *Removal of As(V) from aqueous solutions by iron coated rice husk*, **Fuel Process. Technol.**, **106**, 2013, pp. 511–517. DOI: 10.1016/j.fuproc.2012.09.021.

[31] P. T. Phan, T. T. Nguyen, S. Padungthon, T. Nguyen Thi, and N. N. Huy, *A Novel Conjugate Mechanism for Enhancing the Adsorption Capacity of Amine-Functionalized Activated Rice Husk Ash for Simultaneous Removal of Organics and Anions in Wastewater: Experimental and Theoretical Explanations*, **ACS Omega**, **7(33)**, 2022, pp. 28866–28874. DOI: 10.1021/acsomega.2c01955.

[32] T. N. Tuyen *et al.*, *Treatment of fluoride in well-water in Khanhhoa, Vietnam by aluminum hydroxide coated rice husk ash,* **Green Process. Synth.**, **5(5)**, 2016, pp. 479–489. DOI: 10.1515/gps-2016-0043.

[33] M. U. Dao, H. Y. Hoang, A. K. Tran, and H. H. Cong, *Assessment and treatment of floodwater in the Vietnamese Mekong Delta using a simple filter system based on silver nanoparticles coated onto activated carbon derived from rice husk*, **RSC Adv.**, **11(63)**, 2021, pp. 39838–39847. DOI: 10.1039/d1ra06722b.

Received: June 03, 2023
Accepted: July 18, 2023