USING SUGARCANE BAGASSE AS AN ADSORBENT MATERIAL TO REMOVE IRON FROM WATER

ABSTRACT

This study evaluates the effectiveness of chemically treated sugarcane bagasse as an adsorbent for iron removal from water. The bagasse was modified using sodium hydroxide and citric acid, and its adsorption capabilities were characterized. Batch adsorption experiments were conducted to determine the impact of initial iron concentration, contact time, pH, and adsorbent dosage. Results indicated that the treated sugarcane bagasse exhibited a significantly higher iron adsorption capacity compared to the raw material, with an enhancement factor of 1.7. Optimal conditions were identified as a contact time of 100 minutes, a pH of 3, and an adsorbent dosage of 1.5 grams. Adsorption isotherms were best described by the Langmuir model, yielding a maximum adsorption capacity (q_{max}) of 15.57 mg/g. Additionally, dynamic adsorption tests showed that the adsorbent could be reused effectively, with a desorption efficiency of 75.20%. These findings demonstrate that chemically treated sugarcane bagasse is a viable, cost-effective, and environmentally friendly option for iron removal in water treatment.

Keywords: Sugarcane bagasse, Adsorbent,Iron removal, Water treatment, Adsorption capacity, Desorption efficiency

INTRODUCTION

The contamination of water by heavy metals, particularly iron, is a pressing environmental and public health issue globally. Iron, while essential in trace amounts for various biological functions, can lead to significant problems when present in excessive concentrations. High levels of iron in water are associated with issues such as unpleasant metallic taste, discoloration, and potential health risks, including damage to organs and oxidative stress in the human body. Addressing iron contamination in water is therefore crucial to ensuring both environmental sustainability and public health.

Traditional methods of iron removal from water, such as chemical precipitation, ion exchange, and membrane filtration, have proven effective but are often limited by high operational costs, the need for complex infrastructure, and the generation of secondary pollutants. These limitations have driven the search for alternative methods that are both cost-effective and environmentally friendly.

In this context, the use of agricultural by-products as adsorbent materials has gained significant attention, especially in countries like Vietnam, where agriculture plays a crucial role in the economy. Sugarcane bagasse—a fibrous residue left after the extraction of juice from sugarcane—is particularly promising due to its abundance, low cost, and potential adsorptive properties. In Vietnam, sugarcane (Saccharum officinarum) is a key agricultural crop, especially in the Mekong Delta region, which is a major hub for sugar production. The Vietnamese sugar industry generates millions of tons of bagasse annually. However, much of this by-product remains underutilized or is disposed of through environmentally harmful methods such as burning. By exploring the use of sugarcane bagasse as an adsorbent material, not only can Vietnam address the issue of water contamination, particularly by iron, but it can also find

sustainable ways to manage agricultural waste, thereby enhancing both environmental and economic outcomes.

Sugarcane bagasse is composed mainly of cellulose (32–45%), hemicellulose (20–32%), and lignin (17–32%), components that are known for their adsorptive capabilities. These materials provide a high surface area and various functional groups that can effectively bind and remove heavy metals from contaminated water. The potential of sugarcane bagasse as an adsorbent material has been explored in the removal of several heavy metals, including lead (Pb), zinc (Zn), copper (Cu), and cadmium (Cd). However, its application in the removal of iron has received relatively less attention, despite iron being one of the most prevalent contaminants in water systems.

This study aims to investigate the use of sugarcane bagasse as an adsorbent for the removal of iron from water. The research focuses on optimizing the preparation and characterization of sugarcane bagasse to maximize its adsorption capacity. Additionally, the study evaluates the performance of the bagasse under various environmental conditions, such as pH levels, iron concentrations, and contact time. The findings from this research are expected to contribute to the development of a low-cost, sustainable method for improving water quality, particularly in regions where traditional treatment methods are either unavailable or too costly.

Furthermore, there is a need for continued research in this field. Future studies should explore the long-term stability and reusability of sugarcane bagasse as an adsorbent, as well as the potential benefits of chemical modifications to enhance its efficiency. Addressing these aspects will advance the application of sugarcane bagasse in large-scale water treatment processes, offering a sustainable solution to a global environmental challenge.

MATERIALS AND METHODS

MATERIAL

This methodology is based on the study conducted by Le HuuThieng and Hoang Ngoc Hien (2008), in which sugarcane bagasse was processed to create an adsorbent material for the removal of Cu^{2+} and Pb^{2+}. Following a similar approach, sugarcane bagasse was collected and processed through the following steps to create the adsorbent material:

Step 1: Sugarcane bagasse was cut into small pieces of 5 cm, washed twice with hot distilled water for 30 minutes to remove all natural sugars, dried at 100ºC for 5 hours, ground to a size of 1 mm, and then filtered through filter paper to obtain the raw material.

Step 2: 80 g of the prepared bagasse was added to 1 liter of 0.1M NaOH solution and stirred for 1 hour at room temperature. It was then thoroughly washed and stirred in distilled water for 30 minutes at room temperature. This process was repeated until the alkaline residue was completely removed (checked using pH indicator paper).

Step 3: The cleaned bagasse was added to 500 ml of 0.4M citric acid solution. The citric acid-bagasse suspension was allowed to react for 48 hours at room temperature.

Step 4: The bagasse was then filtered from the citric acid, dried at 60ºC for 5 hours, and activated at 120ºC for 8 hours.

Step 5: The activated material was washed by soaking in 1 liter of distilled water for 1 hour, repeated about 3 times to remove any residual citric acid. It was then dried again at 60ºC for 6 hours and stored in a glass container with a lid.

METHODS

Iron determination method

The total iron concentration in the samples was determined using a standard spectrophotometric method, where iron (III) forms a colored complex with potassium thiocyanate (KSCN).The absorbance of the complex was measured at a wavelength of 440 nm, following the established procedures for iron analysis.

Construction of the iron calibration curve

A calibration curve was constructed using a series of standard iron(III) solutions, with absorbance measurements taken at 440 nm. The linear relationship between iron concentration (C, mg/l) and absorbance (ABS) was used to determine the iron content in the samples, with a regression coefficient (R^2) of 0.994. The relationship between the iron (III) concentration and absorbance is shown in Table 1

Table 1: Results of the Iron standard curve determination

Volume of Fe^{3+}	C (mg/l)	ABS
0	0	0
2	0.04	0.045
4	0.08	0.120
6	0.12	0.194
10	0.2	0.346

Investigation of adsorption capacity of raw material and adsorbent material

To compare the adsorption capacities of the raw material and the adsorbent material, the following procedure is carried out:

Preparation: Prepare two 250 ml Erlenmeyer flasks.

Addition of materials: Add 1 g of raw material to the first flask and 1 g of adsorbent material to the second flask.

Addition of iron solution: Add 100 ml of a 20 mg/l iron solution with a pH of 1 to each flask.

Shaking: Shake the flasks on a shaker for 60 minutes, then filter the contents using filter paper.

Filtration and analysis: Collect the filtrate and proceed with the analysis as described in the analytical procedure.

Investigation of adsorption equilibrium time

To investigate the effect of adsorption equilibrium time on the adsorption process, the following procedure is performed:

Preparation: Prepare seven 250 ml Erlenmeyer flasks.

Addition of materials: Add 1 g of adsorbent material to each flask and 100 ml of a 20 mg/l iron solution with a pH of 1.

Shaking: Shake the flasks on a shaker for different time intervals: 20, 40, 60, 80, 100, 120, and 140 minutes. After each time interval, filter the contents using filter paper.

Filtration and analysis: Collect the filtrate and proceed with the analysis as outlined in the analytical procedure.

Investigation of the effect of adsorbent mass on the adsorption process

To investigate the effect of adsorbent mass on the adsorption process, the following procedure is carried out:

Preparation: Prepare six 250 ml Erlenmeyer flasks and number them sequentially.

Addition of adsorbent: Add 0.4, 0.7, 1.0, 1.5, 1.9, and 2.3 g of adsorbent material to each flask, respectively. Then, add 100 ml of a 20 mg/l iron solution with a pH of 1 to each flask.

Shaking and equilibration: Shake the flasks for a period sufficient to reach adsorption equilibrium. After equilibration, filter the contents using filter paper.

Analysis: Determine the iron concentration in the filtrate after treatment.

Investigation of the effect of pH on the adsorption capacity of the material

To study the effect of pH on the adsorption capacity of the material, the following procedure is performed:

Preparation: Prepare five 250 ml Erlenmeyer flasks and number them sequentially.

Addition of materials: Add 100 ml of a 20 mg/l iron solution and 1.5g of adsorbent material to each flask.

pH adjustment: Adjust the pH of each flask to different values: 1, 2, 3, 4, and 5.

Shaking and equilibration: Shake the flasks for a period sufficient to reach adsorption equilibrium. After equilibration, filter the contents using filter paper.

Analysis: Measure the iron concentration in the filtrate to determine the effect of pH on the adsorption capacity.

Investigation of the adsorption load dependency on equilibrium concentration

To investigate the dependency of the adsorption load on the equilibrium concentration of the material, the following steps are carried out:

Preparation: Prepare eight 250 ml Erlenmeyer flasks and number them from 1 to 8.

Preparation of iron solutions: Prepare iron solutions with different concentrations: 20, 40, 60, 80, 100, 120, 140, and 160 mg/l.

Addition of materials: Add 100 ml of each iron solution with the specified concentration and 1.5g of adsorbent material to each flask.

pH adjustment: Adjust the pH to the optimal value for each flask and shake them for a period sufficient to reach adsorption equilibrium.

Filtration and analysis: Filter the contents of each flask and determine the iron concentration in the filtrate to assess the effect of equilibrium concentration on adsorption load.

Investigation of the desorption capability of the adsorbent material

Add 100 ml of a 20 mg/l iron solution and 1.5g of the adsorbent material (optimal mass) to a 250 ml Erlenmeyer flask.

Shake the flask for 100 minutes.

Measure the iron concentration in the solution after treatment to determine the amount of iron adsorbed by the material.

Perform desorption by treating the adsorbent material with 100 ml of 1M HNO□ solution.

Repeat the desorption process three times, using fresh 100 ml portions of 1M HNO□ for each desorption step.

Measure the Fe^{3+} concentration in the desorption solutions using the spectrophotometric method.

Calculate the amount of iron desorbed from the adsorbent material.

Investigation of the regeneration capability of the adsorbent material

Add 100 ml of a 20 mg/l iron solution to a 250 ml Erlenmeyer flask along with 1.5g of the adsorbent material that has previously undergone desorption.

Adjust the pH to the optimal value for adsorption.

Shake the flask for a period sufficient to reach adsorption equilibrium.

Filter the contents of the flask.

Determine the iron concentration in the filtrate after treatment to evaluate the adsorption capacity of the regenerated material.

Use statistical methods to process the obtained data, calculate the maximum adsorption capacity, and analyze the experimental adsorption data using the Langmuir isotherm model. The maximum adsorption capacity q (mg/g) and adsorption efficiency H (%) of the adsorbent material with respect to the adsorbate solution are calculated using the following formulas:

$$q = \frac{C_o - C_e}{m} \times V$$

$$H = \frac{C_o - C_e}{C} \times 100$$

C□, C_e: initial and final concentrations of the adsorbate solution (mg/l)

V: volume of the adsorbate solution (l)

m: mass of the adsorbent material (g)

RESULTS AND DISCUSSION

Weigh 1 g of each type of raw material and adsorbent material separately into two Erlenmeyer flasks. Add 100 ml of a 20 mg/l iron solution to each flask. Shake the flasks for 60 minutes, then filter the contents and proceed with the analysis as described. The results are presented in Table 2.

Table 2: Adsorption parameters of the raw material and the adsorbent material

Adsorbate	C_o(mg/l)	ABS	C_e(mg/l)	Efficiency (%)
Raw Material	20	0.989	14.01	29.95
Material	20	0.69	9.79	51.05

The results in Table 2 show that both the raw material and the adsorbent material have the ability to adsorb iron. However, the adsorption efficiency of the adsorbent material is 1.7 times higher than that of the raw material. This indicates that the material, after modification with citric acid, has become a more porous adsorbent compared to the initial sugarcane bagasse, with a larger surface area and therefore better adsorption performance.

Add 1 g of the adsorbent material to each of seven numbered 250 ml Erlenmeyer flasks. Then, add 100 ml of a 20 mg/l iron solution to each flask. Shake the flasks on a shaker for different time intervals: 20, 40, 60, 80, 100, 120, and 140 minutes. After shaking, filter the

contents and determine the remaining iron concentration in the solution using the spectrophotometric method. The results are presented in Table 3.

Table 3: Effect of time on Iron adsorption process

C_o(mg/l)	Time (minutes)	ABS	C_e(mg/l)	Efficiency (%)
20	20	0.891	12.61	36.95
20	40	0.802	11.34	43.3
20	60	0.694	9.79	51.05
20	80	0.613	8.67	56.65
20	**100**	**0.562**	**7.97**	**60.15**
20	120	0.551	7.89	60.55
20	140	0.542	7.83	60.85

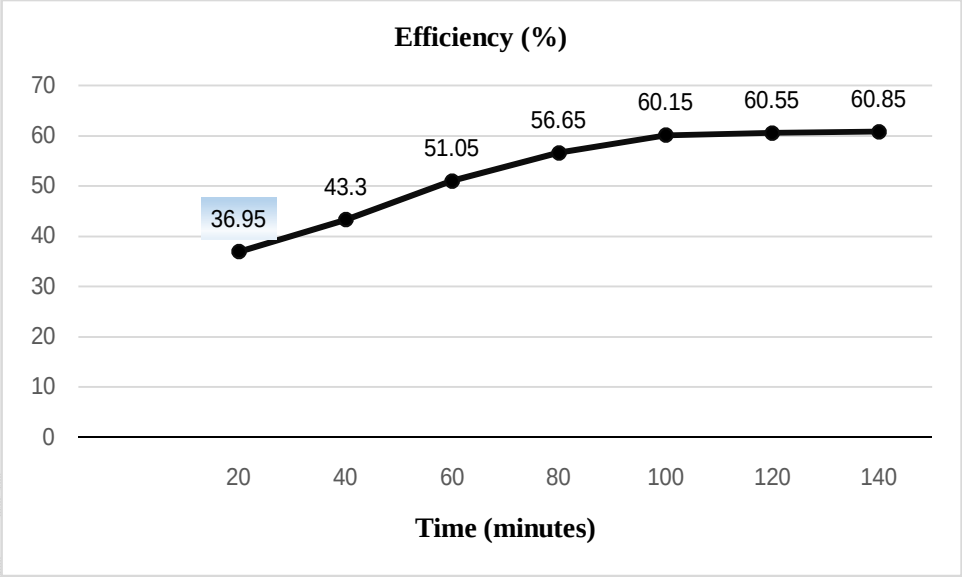

Figure 1: Effect of time on Iron adsorption process

Table 3 and Figure 1 indicate that the adsorption efficiency increases rapidly as the adsorption time extends from 20 to 100 minutes. Beyond 100 minutes, the efficiency of the adsorbent increases only slightly and not significantly. Therefore, an appropriate adsorption equilibrium time for subsequent investigations is 100 minutes

Prepare 6 Erlenmeyer flasks, each with a volume of 250 ml, and number them from 1 to 6. Add 100 ml of a standard iron solution with a concentration of 20 mg/l to each flask, and then add 0.4, 0.7, 1.0, 1.5, 1.9, and 2.3 g of adsorbent material to flasks 1 through 6, respectively.

Shake the flasks on a shaker for 100 minutes (the adsorption equilibrium time selected above), then filter and determine the residual iron concentration in the solution. The results are presented in Table 4

Table 4: Effect of adsorbent mass on Iron adsorption process

C_o	Adsorbent mass	ABS	C_e(mg/l)	Efficiency(%)
20	0.4	0.842	11.91	40.45
20	0.7	0.723	10.26	48.7
20	1.0	0.573	8.0	60.0
20	**1.5**	**0.414**	**5.89**	**70.55**
20	1.9	0.405	5.71	71.45
20	2.3	0.392	5.61	71.95

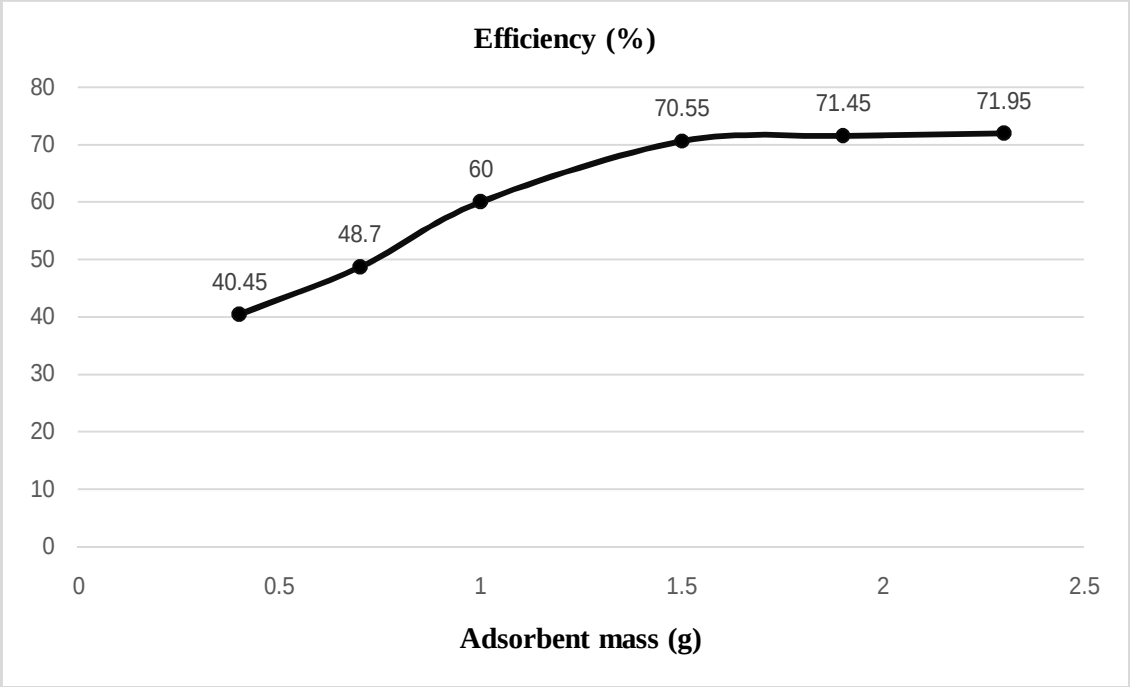

Figure 2: Effect of adsorbent mass on Iron adsorption process

The results show that as the amount of adsorbent material increases, the adsorption efficiency of iron also increases. When the amount of material increases from 0.4 to 1.5g, the adsorption efficiency rises rapidly. Further increasing the amount of adsorbent material continues to improve the iron adsorption efficiency, but the increase is slow and not significant. Therefore, the optimal amount of adsorbent material for subsequent studies is 1.5g.

Add 1.5g of adsorbent material to each of the 5 Erlenmeyer flasks with a volume of 250 ml, and then add 100 ml of a standard iron solution with a concentration of 20 mg/l to each flask. Use dilute NaOH and H_2SO_4 solutions to adjust the pH of the solutions to the respective values of 1, 2, 3, 4, and 5. Shake the flasks for 100 minutes (the optimal adsorption time). Filter the solutions and determine the residual iron concentration. The results are presented in Table 5.

Table 5: Effect of pH on Iron adsorption process

pH	ABS	C_e(mg/l)	Efficiency (%)
1	0.433	6.16	69.2
2	0.352	5.01	74.95
3	**0.264**	**3.67**	**81.65**
4	0.171	2.41	87.95
5	0.135	1.91	90.45

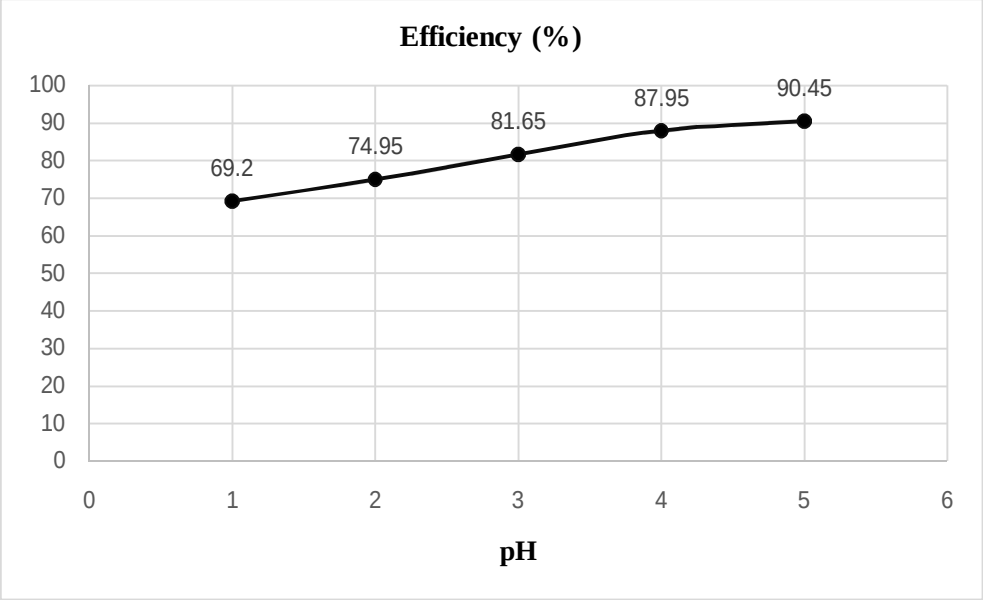

Figure 3: Effect of pH on Iron adsorption process

The results show that as the pH increases, the iron adsorption capacity of the material also increases (the treatment efficiency improves). However, since $T_{Fe(OH)\square} = 1.1 \times 10^{-36}$, Fe^{3+} starts to precipitate when the pH exceeds 3. Therefore, at pH > 3, the efficiency of Fe^{3+} removal by the adsorbent material is not accurate (due to Fe^{3+} both precipitating and being adsorbed). Consequently, a pH of 3 is selected for subsequent research processes.

Take 8 Erlenmeyer flasks with a volume of 250 ml and number them from 1 to 8. Add 100 ml of iron solution with varying concentrations (20, 40, 60, 80, 100, 120, 140, and 160 mg/l) to each flask, and add 1.5g of the adsorbent material (the optimal amount). Adjust the pH to the

optimal value of pH = 3 and shake the flasks for 100 minutes. Filter the solutions and determine the residual iron concentration. The results are presented in Table 6.

Table 6: Results of determining the maximum adsorption capacity of the material at Iron equilibrium concentration

C_o(mg/l)	ABS	C_e(mg/l)	Adsorption loadq(mg/g)	Ratio of C_e/q
20	0.349	3.5	1.1	3.18
40	0.563	8.01	2.13	3.75
60	0.861	12.2	3.18	3.82
80	1.167	16.5	4.23	3.89
100	1.493	21.1	5.26	4.01
120	1.92	27.1	6.19	4.37
140	2.481	35.0	7.0	5.0
160	3.37	47.5	7.5	6.33

The experimental results indicate that the adsorption of Fe^{3+} is well described by the Langmuir isotherm model, both in the high concentration range and the low concentration range.

According to the Langmuir isotherm equation, we have: $tg\alpha = 1/q_{max}$

From the equation representing the dependence of C_f/qonC_f:$tg\alpha=0.0642$

From this, we derive: $q_{max} = 15.57$ (mg/g)

Take 100 ml of a standard iron solution with a concentration of 20 mg/l and 1.5g of the adsorbent material (the optimal amount) and place them in a 250 ml Erlenmeyer flask. Shake for 100 minutes at pH = 3. Filter the solution after shaking, measure the optical density of the resulting solution, and calculate the amount of Fe^{3+} adsorbed by the material. Then, desorb the iron from the material using 100 ml of 1M HNO_3 solution in three separate extractions. The results are presented in Tables 7 and 8.

Table 7: Results of Fe^{3+} adsorption by the adsorbent material

Element	C_o(mg/l)	C_e (mg/l)	Efficiency (%)
Fe^{3+}	20	3.81	80.95

Table 8: Results of desorption of the adsorbent material using 1M HNO_3

Number of washings	Amount of Fe^{3+} adsorbed in the material (mg)	Amount of Fe^{3+} desorbed (mg)	Efficiency (%)
First wash	16.187	9.442	58.33
Second wash	6.745	3.816	81.91
Third wash	2.929	1.988	94.24

From the above data, it is evident that the desorption capability of the adsorbent material using 1M HNO□ is quite good. Initially, the adsorbent material contained 16.187 mg of Fe^{3+} . After being desorbed three times, only 0.941 mg of Fe^{3+} remained, resulting in a desorption efficiency of 94.24%.

Take 100 ml of a standard iron solution with a concentration of 20 mg/l and 1.5g of the previously desorbed adsorbent material and place them in a 250 ml Erlenmeyer flask. Shake for 100 minutes at pH = 3. The results are presented in Table 9.

Table 9: Results of adsorbent material regeneration

Adsorbent material	C_o(mg/l)	C_e(mg/l)	Efficiency (%)
Sugarcane bagasse	20	4.96	75.20

The above results indicate that the regenerability of the adsorbent material is quite promising, with an efficiency of 75.20%

CONCLUSION

This study demonstrates the potential of sugarcane bagasse as an effective adsorbent material for the removal of iron (Fe^{3+}) from water. The adsorption process was found to be well described by the Langmuir isotherm model, indicating monolayer adsorption on a homogenous surface. The optimal adsorption conditions were determined to be an adsorbent dosage of 1.5g, an initial iron concentration of 20 mg/l, a pH of 3, and an equilibrium time of 100 minutes, achieving a maximum adsorption capacity (q_{max}) of 15.57 mg/g.

Further experiments revealed that the adsorbent can be effectively regenerated using 1M HNO_3 , with a desorption efficiency of 94.24%. The regenerated material retained a significant portion of its adsorption capacity, exhibiting a regenerability efficiency of 75.20% after three desorption cycles.

These results indicate that sugarcane bagasse is not only a cost-effective and environmentally friendly adsorbent for iron removal from water but also demonstrates good potential for reuse and regeneration. Future research should focus on scaling up the process and evaluating the performance of sugarcane bagasse in real-world water treatment scenarios, considering various environmental conditions and the presence of other contaminants.

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Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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