

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

ABSTRACT

This study investigates the potential of sugarcane bagasse as an adsorbent material for the removal of iron from water. The research focuses on the preparation and characterization of sugarcane bagasse adsorbent, examining its adsorption capacity and efficiency. Batch adsorption experiments were conducted to evaluate the influence of various parameters, including initial iron concentration, contact time, pH, and adsorbent dosage. The results demonstrated that sugarcane bagasse possesses significant iron adsorption capabilities, with optimal conditions identified for maximum removal efficiency. The adsorption isotherms were analyzed using Langmuir model, and kinetic studies were performed to understand the adsorption mechanisms. The findings suggest that sugarcane bagasse is a cost-effective and environmentally friendly alternative for iron removal in water treatment applications.

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

INTRODUCTION

Water contamination by heavy metals, particularly iron, poses significant environmental and health challenges worldwide. Iron, though an essential element for biological processes, can become problematic in high concentrations, leading to issues such as water discoloration, metallic taste, and adverse health effects. Conventional methods for iron removal from water, including chemical precipitation, ion exchange, and membrane filtration, often involve high operational costs and complex procedures.

In recent years, there has been growing interest in the use of low-cost, sustainable materials for water purification. Agricultural by-products have emerged as promising alternatives due to their availability, cost-effectiveness, and environmental friendliness. Among these, sugarcane bagasse, a by-product of the sugar industry, has gained attention for its potential as an adsorbent material.

Sugarcane bagasse consists primarily of cellulose, hemicellulose, and lignin, components that provide a high surface area and functional groups capable of adsorbing various contaminants. Utilizing sugarcane bagasse for water treatment not only addresses the issue of agricultural waste disposal but also offers a sustainable solution for water purification.

This study aims to explore the effectiveness of sugarcane bagasse as an adsorbent for the removal of iron from water. The research focuses on the preparation and characterization of sugarcane bagasse adsorbent, as well as the evaluation of its adsorption capacity under various conditions. By investigating the potential of this agricultural by-product, we seek to contribute to the development of cost-effective and eco-friendly methods for improving water quality.

MATERIALS AND METHODS

MATERIAL

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 100°C 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 60°C for 5 hours, and activated at 120°C 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 60°C for 6 hours and stored in a glass container with a lid.

METHODS

Iron determination method

All iron in the sample is reduced to iron (III) by boiling with KMnO_4 in an acidic medium. Subsequently, the iron (III) reacts with KSCN reagent to form a stable complex with an orange-red color. The color intensity is proportional to the iron content in the sample. The maximum absorption coefficient is observed at a wavelength of 440 nm.

Construction of the iron calibration curve

Determination of Iron (III) concentration: The concentration of iron (III) in the solution is determined using the spectrophotometric method.

Calibration curve: The calibration curve is a straight line that illustrates the linear relationship between the concentration of iron (III) (C, in mg/L) and the absorbance (ABS) measured at a wavelength of 440 nm.

Procedure: Samples are analyzed to determine their absorbance values at 440 nm, and a series of standard solutions is used to construct the calibration curve. 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	0,12
6	0,12	0,194
10	0,2	0,346

The calibration curve is described by the equation $y=bx+a$ where y is the absorbance (A) and x is the concentration (C). The regression coefficient R^2 is 0.994

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 1.5 g 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 1.5 g 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 1.5 g 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 HNO₃ solution.

Repeat the desorption process three times, using fresh 100 ml portions of 1M HNO₃ for each desorption step.

Measure the Fe³⁺ 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 1.5 g 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:

$$q = \frac{C_0 - C_{cb}}{m} * V$$

$$H = \frac{C_0 - C_{cb}}{C} * 100$$

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	Co(mg/l)	ABS	Cf(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

Co (mg/l)	Time (minutes)	ABS	Cf (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

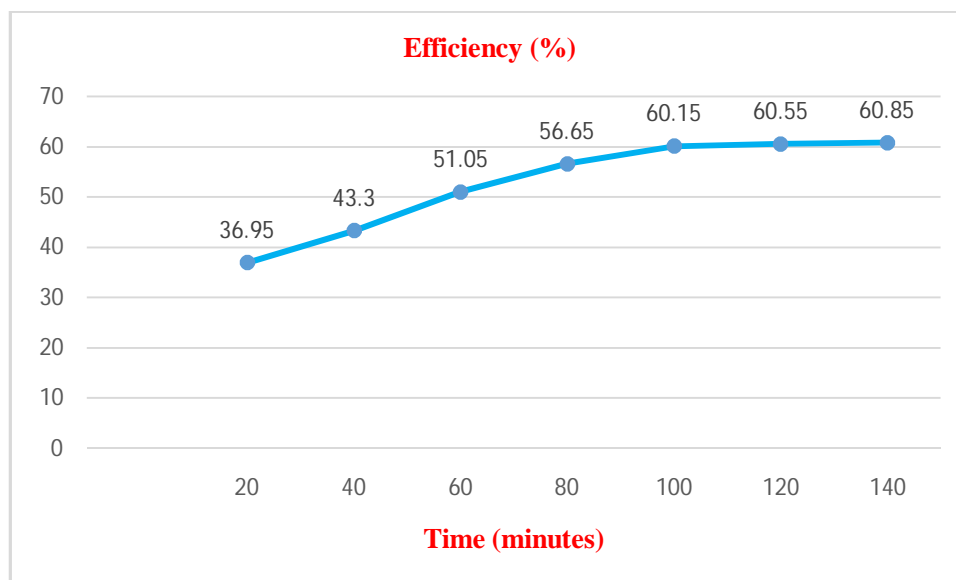


Figure 1: Effect of time on Iron adsorption process

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 grams 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_f (mg/l)	Efficiency (%)
20	0,4	0,842	11,91	40,45
20	0,7	0,723	10,26	48,7
20	1	0,573	8	60
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

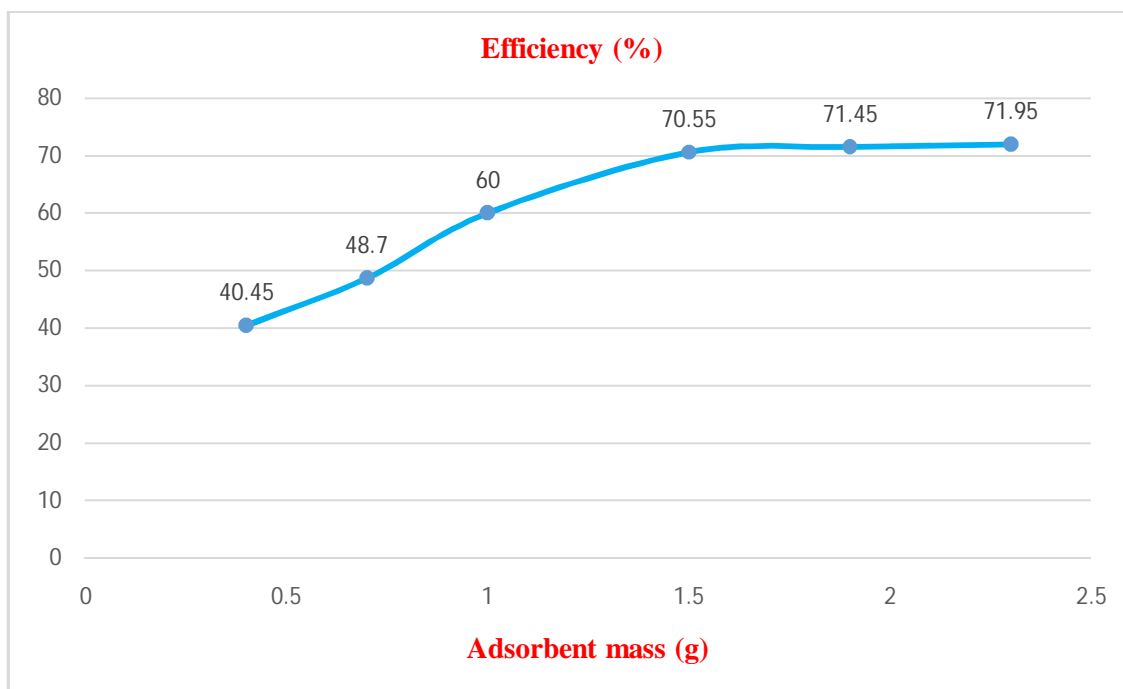


Figure 2: Effect of adsorbent mass on Iron adsorption process

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 1.5 grams, 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 1.5 grams

Add 1.5 grams 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 H₂SO₄ 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	Cf(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

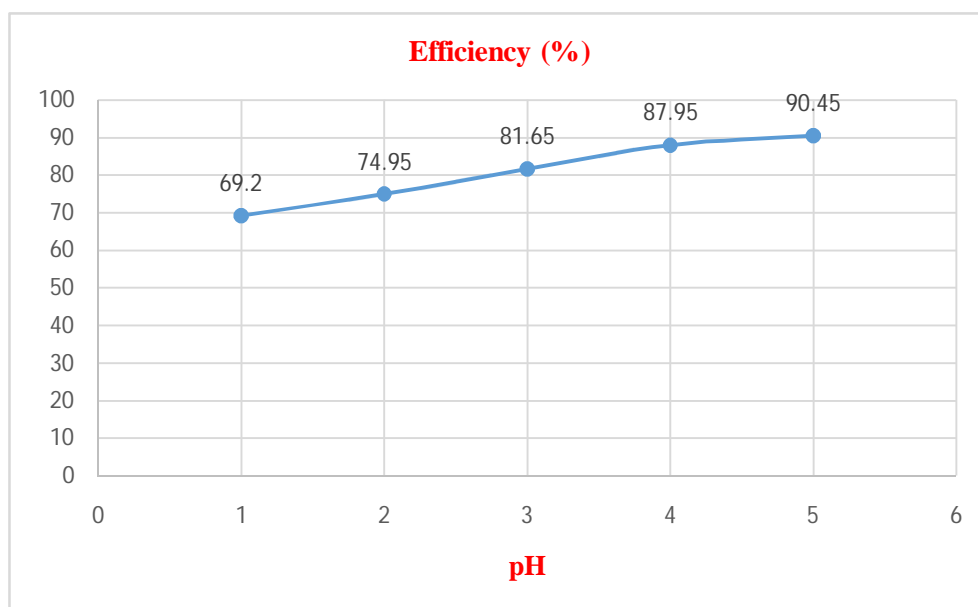


Figure 3: Effect of pH on Iron adsorption process

The results show that as the pH increases, the iron adsorption capacity of the material also increases (the treatment efficiency improves). However, since $TFe(OH)_3 = 1.1 \times 10^{-36}$, 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 1.5 grams 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

Co(mg/l)	ABS	Cf (mg/l)	Adsorption loadq(mg/g)	Ratio of Cf/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	7	5
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/q on C_f we have: $tg\alpha = 0,0642$

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 1.5 grams 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	Co(mg/l)	Cf (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_3 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 1.5 grams 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	Co(mg/l)	Cf(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 1.5 grams, 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 material 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.

REFERENCES

1. Praipipat, Pornsawai, PimployNgamsurach, and AmornratSanghuayprai. "Modification of sugarcane bagasse with iron (III) oxide-hydroxide to improve its adsorption property for removing lead (II) ions." *Scientific Reports* 13.1 (2023): 1467.
2. Elwakeel, Khalid Z., Gamal O. El-Sayed, and Susan M. Abo El-Nassr. "Removal of ferrous and manganous from water by activated carbon obtained from sugarcane bagasse." *Desalination and Water Treatment* 55.2 (2015): 471-483.
3. Pehlivan, E., et al. "Sugarcane bagasse treated with hydrous ferric oxide as a potential adsorbent for the removal of As (V) from aqueous solutions." *Food chemistry* 138.1 (2013): 133-138.
4. Buthiyappan, Archina, Jayaprina Gopalan, and Abdul Aziz Abdul Raman. "Synthesis of iron oxides impregnated green adsorbent from sugarcane bagasse: Characterization and evaluation of adsorption efficiency." *Journal of environmental management* 249 (2019): 109323.
5. Buthiyappan, Archina, Jayaprina Gopalan, and Abdul Aziz Abdul Raman. "Synthesis of iron oxides impregnated green adsorbent from sugarcane bagasse: Characterization and evaluation of adsorption efficiency." *Journal of environmental management* 249 (2019): 109323.

6. Zhu, Y., et al. "Adsorption of chromium (VI) from aqueous solution by the iron (III)-impregnated sorbent prepared from sugarcane bagasse." *International Journal of Environmental Science and Technology* 9 (2012): 463-472.
7. Bai, Liji, et al. "Preparation of sugarcane bagasse biochar/nano-iron oxide composite and mechanism of its Cr (VI) adsorption in water." *Journal of Cleaner Production* 320 (2021): 128723.
8. Soliman, Ezzat M., Salwa A. Ahmed, and Aliaa A. Fadl. "Reactivity of sugar cane bagasse as a natural solid phase extractor for selective removal of Fe (III) and heavy-metal ions from natural water samples." *Arabian Journal of Chemistry* 4.1 (2011): 63-70.
9. Jiang, Wenyan, et al. "Adsorption of cationic dye from water using an iron oxide/activated carbon magnetic composites prepared from sugarcane bagasse by microwave method." *Environmental technology* 42.3 (2021): 337-350.
10. Balaji, R., S. Sasikala, and G. Muthuraman. "Removal of Iron from drinking/ground water by using agricultural Waste as Natural adsorbents." *International Journal of Engineering and Innovative Technology* 3.12 (2014): 43-46.
11. Montero, José Ignacio Z., et al. "High efficiency removal of As (III) from waters using a new and friendly adsorbent based on sugarcane bagasse and corncob husk Fe-coated biochars." *Ecotoxicology and Environmental Safety* 162 (2018): 616-624.
12. Halysh, Vita, et al. "Sugarcane bagasse and straw as low-cost lignocellulosic sorbents for the removal of dyes and metal ions from water." *Cellulose* 27 (2020): 8181-8197.
13. Yogeshwaran, V., and A. K. Priya. "Experimental studies on the removal of heavy metal ion concentration using sugarcane bagasse in batch adsorption process." *Desalination and Water Treatment* 224 (2021): 256-272.
14. Wannahari, R., et al. "Sugarcane bagasse derived nano magnetic adsorbent composite (SCB-NMAC) for removal of Cu²⁺ from aqueous solution." *ARPJ Journal of Engineering and Applied Sciences* 13.1 (2018): 1-9.
15. Sarker, Tushar C., et al. "Sugarcane bagasse: a potential low-cost biosorbent for the removal of hazardous materials." *Clean Technologies and Environmental Policy* 19 (2017): 2343-2362.
16. Da Silva, Leandro G., et al. "Adsorption of Brilliant Red 2BE dye from water solutions by a chemically modified sugarcane bagasse lignin." *Chemical Engineering Journal* 168.2 (2011): 620-628.
17. Ezeonuegbu, Blessing Amaka, et al. "Agricultural waste of sugarcane bagasse as efficient adsorbent for lead and nickel removal from untreated wastewater: Biosorption, equilibrium isotherms, kinetics and desorption studies." *Biotechnology Reports* 30 (2021): e00614.
18. Pereira da Silva, Carine, et al. "Optimization of the Production Parameters of Composites from Sugarcane Bagasse and Iron Salts for Use in Dye Adsorption." *The Scientific World Journal* 2019.1 (2019): 8173429.