IOSR Journal of Applied Chemistry (IOSR-JAC)
e-ISSN: 2278-5736.Volume 19, Issue 4 Ser. I (April. 2026), PP 45-53
www.iosrjournals.org

Impregnated Activated Carbon Of Sugarcane Bagasse As Potential Adsorbent For The Removal Of Copper Metal Ions From The Industrial Effluent In Batch Mode

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Abstract:
Too much discharge of effluent from the industries containing heavy metals to the surroundings of the environment has created a significant problem for our natural water system. Adsorption processes are of great importance for the removal or elimination of heavy metal ions from the effluent which is discharged by the industries. The principal objective of this research was to evaluate the removal of copper metal ions from the industrial effluent using anions impregnated sugarcane bagasse. Sugarcane bagasse collected from the sugarcane processing units and extensively washed using distilled water for the removal of dirt and other water-soluble impurities. Bagasse needs to be dried for 24-26 hours in the oven at 100-105°C. Purified sugarcane bagasse is then converted into activated carbon using muffle furnace at temperature of approximately 400°C for 24 hours. Then activated carbon of sugarcane bagasse is impregnated using sulphuric acid, ortho-phosphoric acid and nitric acid to increase its surface area and porosity. Characterization of anions impregnated sugarcane bagasse is done using SEM, EDX, and FTIR. Impregnated sugarcane bagasse is proposed to be used for the elimination or removal of copper metal ions from industrial effluent.
The Langmuir and Freundlich isotherm models are widely applied to estimate the quantity of adsorbate retained per unit mass of solid adsorbents. The metal effluent samples run over treated bagasse analyzed to ascertain effectiveness of model under varied conditions.

Keywords: *Agricultural waste, adsorption processes, Adsorbents, impregnation, wastewater treatment*

Date of Submission: 14-04-2026 Date of Acceptance: 24-04-2026

I. Introduction:

The pollution in the environment is due to rapid industrialization and extreme usage of inorganic as well as organic chemicals worldwide which leads to generations of hazardous pollutants including toxic heavy metals. The existence of contaminated heavy metals in the in the environment as well in the ground water is a very crucial problem. Heavy metals that's initiated from different types of industries like electroplating, mining, petroleum refining, coal and textile industry, battery manufacturing etc and other industrial effluent that's creates potential destruction of our ecosystem, animal as well as health system in fact at small concentrations [1,2,3]. Industrial effluent is the major origin of pollutants that contain heavy metal ions and that are basically poisonous in nature and that cannot be decomposed. Additionally, heavy toxic metals can be assembled in living tissues that will cause various types of diseases and disorders [4,5]. Thus, the secure and potential effluent treatment containing heavy metal ions is always a great challenge to environments as well as industrialists, and there is a demand for more affordable as well as secure treatments [6].

During the last few decades, a variety of physicochemical methods have been developed to remove pollutants from wastewater. These methods include chemical precipitation, membrane-based separation techniques such as ultrafiltration, nanofiltration, and reverse osmosis, as well as electrodialysis and electrochemical approaches like electrodeposition and electroflotation. In addition, processes such as adsorption, ion exchange, coagulation, and flotation are thoroughly applied for pollutant removal [7]. Among the available techniques for eliminating heavy metal ions, adsorption is considered particularly effective due to its high efficiency in handling concentrated contaminants, broad applicability [8], and environmentally safe nature [9]. Sugarcane is an important tropical crop cultivated extensively in countries like India, Brazil, and China, playing a key role in global sugar production [10]. Brazil ranks as the largest producer, followed by India and China. The byproduct of sugarcane processing, known as bagasse, is an abundant agricultural residue that can be utilized as

a cost-effective adsorbent for removing heavy metals from industrial wastewater. It is mainly composed of lignin (about 20%), hemicellulose (around 25%), and cellulose (approximately 42%) [11].

Sugarcane bagasse is residual byproduct of agricultural waste left after the extraction of sugarcane juice, and it contains unique functional groups and that can be transformed or impregnated chemically to enhance its adsorbent capability. Sugarcane bagasse as well as chemically impregnated sugarcane bagasse can effectively eliminate an extensive range of target adsorbates from industrial effluent as aqueous solution, including hazardous heavy metal ions [12,13], dyes [14], petroleum [15] and phenolic compounds [16].

II. Materials And Methodology:

Materials and chemicals:

All the materials and chemicals used for the impregnation of sugarcane bagasse and preparation of standard solution were of laboratory reagent grade (LR grade). The chemicals which were used for the impregnation of sugarcane bagasse which includes nitric acid (HNO_3), ortho-phosphoric acid (H_3PO_4), sulphuric acid (H_2SO_4) and preparation of standard solution were zinc chloride, sodium chloride, copper sulphate pentahydrate, potassium dichromate were purchased from CDH, Delhi, India. Distilled water was utilized during both sample preparation and standardization to avoid interference from foreign ions.

Preparation of Activated Carbon of Sugarcane bagasse (SB):

Sugarcane bagasse was collected from DCM Shriram Industries Limited, sugarcane factory in Daurala, Uttar Pradesh, India and washed with plenty of distilled water in order to remove the dirt as well as water soluble impurities. After that wet washed sugarcane bagasse was dried under vacuum at 100-105°C for 24-26 hours. The dried sugarcane bagasse was carbonized at 400-405°C in muffle furnace for approximately 24 hours in order to get in the form of activated carbon. After that, the activated carbon cooled to room temperature under nitrogen atmosphere.

Anion Impregnated Adsorbents Preparation Using Sugarcane Bagasse activated carbon and Acids

1. **Preparation of anion impregnated Adsorbent Using Ortho-Phosphoric Acid (SBOPA/SBPA):** Soaked the activated carbon form of sugarcane bagasse with 8 molar concentrations of ortho-phosphoric acid for 30-32 hours at room temperature. After this, filtered the adsorbent using Buckner funnel and washed with distilled water till pH is 7 (neutral). Unloaded the adsorbent and dried at 200-205°C for 22-24 hours. The adsorbent was cooled to room temperature under nitrogen atmosphere.
2. **Preparation of anion impregnated Adsorbent Using Nitric Acid (SBNA):** Soaked the activated carbon form of sugarcane bagasse with 8 molar concentrations of Nitric acid for 30-32 hours at room temperature. After this, filtered the adsorbent using Buckner funnel and washed with distilled water till pH is 7 (neutral). Unloaded the adsorbent and dried at 200-205°C for 22-24 hours. The adsorbent was cooled to room temperature under nitrogen atmosphere.
3. **Preparation of anion impregnated Adsorbent Using Sulphuric Acid (SBSA):** Soaked the activated carbon form of sugarcane bagasse with 8 molar concentrations of sulphuric acid for 30-32 hours at room temperature. After this, filtered the adsorbent using Buckner funnel and washed with distilled water till pH is 7. Unloaded the adsorbent and dried at 200-205°C for 22-24 hours. The adsorbent was cooled to room temperature under nitrogen atmosphere.

Impregnated Adsorbent Characterization (FTIR, EDX and SEM)

The functional groups that are present on the surface of sugarcane bagasse (SB) before and after impregnation were identified using Fourier Transform Infrared (FTIR) spectroscopy (perkin Elmer, USA). Changes in surface morphology before and after adsorption were explored with Scanning Electron Microscopy (SEM) (Hitachi Model: FlexSEM 1000 II). Elemental composition and percentage distribution were identified using Energy Dispersive X-ray (EDX) analysis (Hitachi Model: FlexSEM 1000 II).

EDX Analysis:

The composition of chemical elements of sugarcane bagasse (SB) and impregnated sugarcane bagasse with nitric acid (SBNA), ortho-phosphoric acid (SBPA/SBOPA) and sulphuric acid (SBSA) are as follows in table1:

Materials	Chemical Elements (% wt)				
	C	O	S	N	P
Sugarcane Bagasse (SB)	57.32	42.68	-	-	-
SBNA	21.92	70.67	-	**7.42**	-
SBPA /SBOPA	36.67	47.35	-	-	**15.99**
SBSA	47.25	30.52	**22.23**	-	-

Table1: The composition of chemical elements

The EDX spectrum analysis of activated carbon of sugarcane bagasse (SB) reveals that the material is dominated by carbon (C), typically more than 55% wt%, along with a smaller proportion of oxygen (O) 42.68, %wt, indicating the effective carbonization of the lignocellulosic precursor. The smaller amount of oxygen content reflects dehydration and removal of volatile components during activation, while the residual oxygen corresponds to surface functional groups such as hydroxyl, carbonyl, and carboxyl moieties.

Upon impregnation using nitric acid-treated activated carbon, the EDX analysis shows the appearance of a nitrogen (N) peak, 7.42 %wt, along with a substantial increase in oxygen content (70.67 %wt), reflecting extensive oxidation of the surface. Nitric acid, being a strong oxidizing agent, introduces various oxygenated and nitrogen-containing functional groups such as nitro ($–NO_2$), carboxyl (–COOH), and hydroxyl (–OH) groups. The observed decrease in carbon content (21.92 %wt) further suggests partial oxidation and disruption of the carbon matrix, leading to the creation of additional surface defects and active sites. These changes result in increased surface polarity and hydrophilicity, which enhance the material's ability to adsorb heavy metal ions through coordination and complexation mechanisms.

In case of phosphoric acid impregnation leads to the appearance of a phosphorus (P) peak (15.99 %wt) in the EDX spectrum, confirming the successful incorporation of phosphorus species into the activated carbon structure. The increase in oxygen content (47.35 % wt) and corresponding decrease in carbon content (36.67 %wt) indicate chemical interaction between the acid and the carbon matrix. The formation of phosphate and polyphosphate groups contributes to crosslinking within the structure, which helps in the development of a well-defined porous network while maintaining structural stability.

Similarly, impregnation with sulphuric acid, the EDX spectrum exhibits the appearance of the sulfur (S) peak (22.23 % wt), confirming the incorporation of sulfur-containing functional groups onto the carbon surface. This is accompanied by slight decrease in carbon percentage (47.25 %wt), indicating oxidation and chemical modification of the carbon framework.

FTIR Analysis:

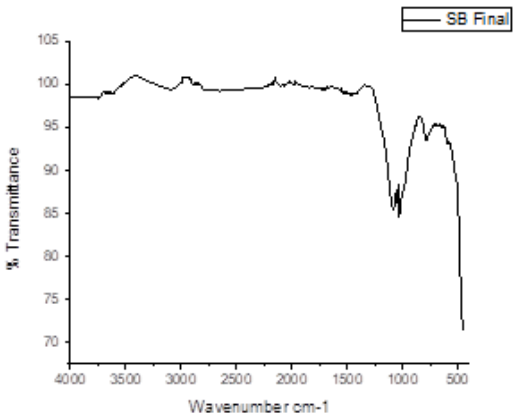

Figure1(a): IR spectra of activated SB

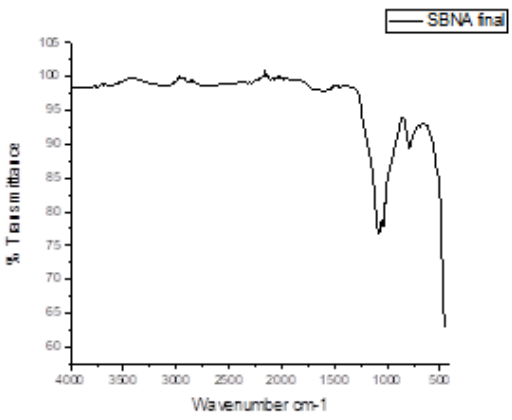

Figure 1(b): IR spectra of SBNA

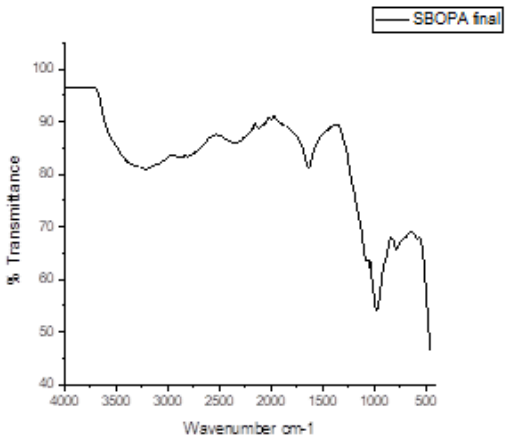

Figure 1(c): IR spectra of SBPA/SBOPA

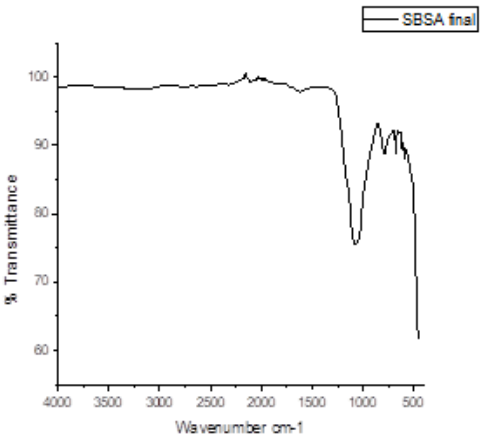

Figure 1(d): IR spectra of SBSA

In figure 1(a) of SB, the spectrum is dominated by fingerprint region peaks (1200–600 cm^{-1}), confirming structural transformation toward carbon-rich material. The strong 1066 cm^{-1} peak reflects retained oxygenated groups (C–O), which are crucial for adsorption properties. The intense 697 cm^{-1} peak indicates aromatic condensation, suggesting partial carbonization and lignin-derived structures. The weakness of peaks around ~1700 cm^{-1} (C=O) implies low carbonyl content, that may be possibly due to thermal decomposition while a broad peak at 2803 cm^{-1} and 3081 cm^{-1} shows the the C-H stretching and O-H stretching respectively. peak at 2803 cm^{-1} shows the C-H stretching, broad peak at 1430 cm^{-1} shows the C=O stretching, a sharp peak at 1076 cm^{-1} shows the C=O stretching and peak at 830 cm^{-1} shows the C=C stretching.

In figure 1(b) SBNA containing nitrate anion, a peak at 671 cm^{-1} shows the nitrogen functional group and a peak at1662 cm^{-1} indicates the oxidized carbonyl groups formed during acid impregnation.

In figure 1(c) SBPA/SBOPA, prominent absorptions at 1113 and 1037 cm^{-1} are assigned to P–O stretching, indicating successful chemical activation and incorporation of oxygenated/phosphorus-containing functional groups. The low-frequency band around 600 cm^{-1} further supports the presence of heteroatom, i.e., phosphorus atom.

In figure 1(d), the FTIR spectrum of SBSA demonstrates successful sulfuric acid activation, evidenced by strong S=O and C–S bands at 1037 cm^{-1} and 678 cm^{-1} respectively.

SEM Images:

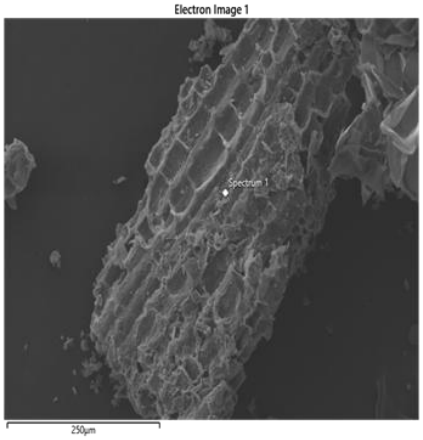

Figure 2(a): SEM Image of SB

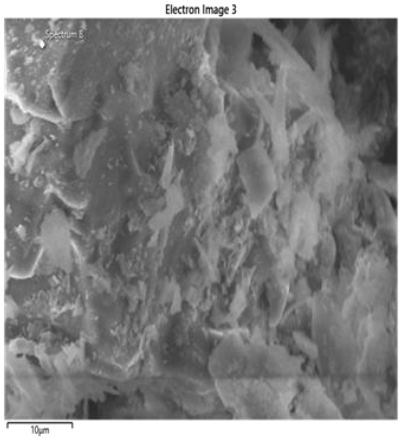

Figure 2(b): SEM image of SBNA

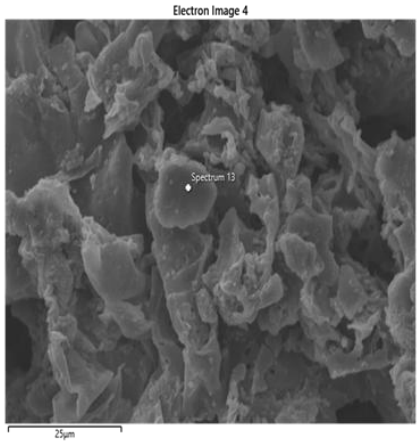

Figure 2(c): IR spectra of SBPA/SBOPA

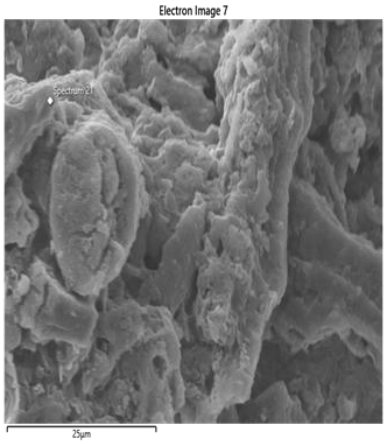

Figure 2(d): IR spectra of SBSA

In figure 2(a) SEM image of SB shows long fibrous structure, compact, smooth surface less porosity while the SEM images of SBNA, SBOPA/SBPA and SBSA in figure 2(b), 2(c) and 2(d), the SEM micrograph after anionic impregnated sugarcane bagasse carbon reveals a highly disordered, flaky, and lamellar morphology with abundant slit-shaped pores. The original lignocellulosic structure is significantly disrupted, indicating strong impregnation. The presence of interconnected mesoporous networks and roughened surfaces suggests enhanced surface area and availability of active sites. This structural evolution is attributed to the dehydrating and cross-linking, making the material highly suitable for adsorption applications due to rough surface and increased porosity.

Preparation of Standard Solution:

Dissolved 800 mg of each sodium chloride, copper sulphate pentahydrate, zinc chloride and potassium dichromate in 2000 ml distilled water. Shaked well the solution to get clear solution. Analysed the standard solution for atomic absorption spectroscopy (AAS).

Experiments for the Treatment of Stock Solution for the removal of Heavy metals in Batch Mode Using activated carbon and impregnated activated carbon of Sugarcane Bagasse Adsorbents:

Treatment of Stock Solution for the removal of Heavy metal ions Using SB Adsorbent:

Took 250 ml of conical flak and weighed 100 g of stock solution in this conical flask and weighed 1.0 g of adsorbent. Added this weighed adsorbent in the conical flask containing stock solution and stirred in magnetic stirrer for 180 min. at 25-30°C. The experiment was exercised at pH of 5, 7 and 9. Filtered the solution using Buckner funnel to get clear solution. Analysed filtrate sample for atomic absorption spectroscopy (AAS) and results are summarized in table2: -

S. No.	Solution Status	Heavy metal ions	Initial Heavy metal ions concentration (ppm)	Adsorbent	Sample quantity & Adsorbent Dose (g)	pH & Temperature (°C)	Contact Time (min)	Heavy metal ions concentration after treatment (ppm)	Removal %age
1.	Standard Solution	Na	395	SB	100 & 1.0	5 & 25-30	180	79	80.0
		K	410					81	80.2
		Zn	390					84	78.5
		Cu	395					82	79.2
		Cr	408					86	78.9
2.	Standard Solution	Na	395	SB	100 & 1.0	7 & 25-30	180	93	76.4
		K	410					94	77.1
		Zn	390					91	76.7
		Cu	395					92	76.7
		Cr	408					95	76.7
3.	Standard Solution	Na	395	SB	100 & 1.0	9 & 25-30	180	105	73.4
		K	410					110	73.2
		Zn	390					101	74.1
		Cu	395					104	73.7
		Cr	408					103	74.7

Table2: Summarizes the removal of heavy metal ions from the stock solution Using SB adsorbent at different pH

Treatment of Stock Solution for the removal of Heavy metal ions Using SBNA Adsorbent:

Took 250 ml of conical flak and weighed 100 g of stock solution in this conical flask and weighed 1.0 g of adsorbent. Added this weighed adsorbent in the conical flask containing stock solution and stirred in magnetic stirrer for 180 min. at 25-30°C. The experiment was exercised at pH of 5, 7 and 9. Filtered the solution using Buckner funnel to get clear solution. Analysed filtrate sample for atomic absorption spectroscopy (AAS) and results are summarized in table3: -

S. No.	Solution Status	Heavy metal ions	Initial Heavy metal ions concentration (ppm)	Adsorbent	Sample quantity & Adsorbent Dose (g)	pH & Temperature (°C)	Contact Time (min)	Heavy metal ions concentration after treatment (ppm)	Removal %age
1.	Standard Solution	Na	395	SBNA	100 & 1.0	5 & 25-30	180	28	92.9
		K	410					31	92.4
		Zn	390					29	92.6
		Cu	395					32	91.9
		Cr	408					31	92.4
2.	Standard Solution	Na	395	SBNA	100 & 1.0	7 & 25-30	180	42	89.4
		K	410					48	88.3
		Zn	390					42	89.2
		Cu	395					46	88.4
		Cr	408					47	88.5
3.	Standard Solution	Na	395	SBNA	100 & 1.0	9 & 25-30	180	58	85.3
		K	410					55	86.6
		Zn	390					56	85.6
		Cu	395					63	84.0
		Cr	408					59	85.5

Table3: Summarizes the removal of heavy metal ions from the stock solution Using SBNA adsorbent at different pH

Treatment of Stock Solution for the removal of Heavy metal ions Using SBSA Adsorbent:

Took 250 ml of conical flask and weighed 100 g of stock solution in this conical flask and weighed 1.0 g of adsorbent. Added this weighed adsorbent in the conical flask containing stock solution and stirred in magnetic stirrer for 180 min. at 25-30°C. The experiment was exercised at pH of 5, 7 and 9. Filtered the solution using Buckner funnel to get clear solution. Analysed filtrate sample for atomic absorption spectroscopy (AAS) and results are summarized in table4: -

S. No.	Solution Status	Heavy metal ions	Initial Heavy metal ions concentration (ppm)	Adsorbent	Sample quantity & Adsorbent Dose (g)	pH & Temperature (°C)	Contact Time (min)	Heavy metal ions concentration after treatment (ppm)	Removal %age
1.	Standard Solution	Na	395	SBSA	100 & 1.0	5 & 25-30	180	30	92.4
		K	410					32	92.2
		Zn	390					31	92.0
		Cu	395					27	93.2
		Cr	408					29	92.9
2.	Standard Solution	Na	395	SBSA	100 & 1.0	7 & 25-30	180	47	88.1
		K	410					48	88.3
		Zn	390					50	87.2
		Cu	395					44	88.9
		Cr	408					52	87.3
3.	Standard Solution	Na	395	SBSA	100 & 1.0	9 & 25-30	180	62	84.3
		K	410					60	85.4
		Zn	390					56	85.6
		Cu	395					61	84.6
		Cr	408					66	83.8

Table4: Summarizes the removal of heavy metal ions from the stock solution Using SBSA adsorbent at different pH

Treatment of Stock Solution for the removal of Heavy metal ions Using SBPA/SBOPA Adsorbent:

Took 250 ml of conical flask and weighed 100 g of stock solution in this conical flask and weighed 1.0 g of adsorbent. Added this weighed adsorbent in the conical flask containing stock solution and stirred in magnetic stirrer for 180 min. at 25-30°C. The experiment was exercised at pH of 5, 7 and 9. Filtered the solution using Buckner funnel to get clear solution. Analysed filtrate sample for atomic absorption spectroscopy (AAS) and results are summarized in table5:

S. No.	Solution Status	Heavy metal ions	Initial Heavy metal ions concentration (ppm)	Adsorbent	Sample quantity & Adsorbent Dose (g)	pH & Temperature (°C)	Contact Time (min)	Heavy metal ions concentration after treatment (ppm)	Removal %age
1.	Standard Solution	Na	395	SBOPA/SBPA	100 & 1.0	5 & 25-30	180	30	92.4
		K	410					34	91.7
		Zn	390					29	92.6
		Cu	395					27	93.2
		Cr	408					30	92.6
2.	Standard Solution	Na	395	SBOPA/SBPA	100 & 1.0	7 & 25-30	180	44	88.9
		K	410					55	86.6
		Zn	390					49	87.4
		Cu	395					46	88.3
		Cr	408					52	87.2
3.	Standard Solution	Na	395	SBOPA/SBPA	100 & 1.0	9 & 25-30	180	72	81.8
		K	410					80	80.5
		Zn	390					78	80.0
		Cu	395					83	79.0
		Cr	408					90	77.9

Table5: Summarizes the removal of heavy metal ions from the stock solution Using SBOPA/SBPA adsorbent at different pH

Collection of Industrial Effluent / untreated wastewater:

Sample of industrial effluent was collected from untreated waste water channel of Chemical Plant of DCM Shriram Industries, Uttar Pradesh, Meerut. The sample was collected in five-litre plastic bottles, The pH of the effluent was determined and found 7.10.

Treatment of Industrial Effluent for the removal of copper metal ions Using SBSA, SBPA/SBOPA, SBSA Adsorbents:

Took 250 ml of conical flask and weighed 100 g of industrial effluent containing copper metal ions in this conical flask and weighed 1.0 g of adsorbent. Added this weighed adsorbent in the conical flask containing stock solution and stirred in magnetic stirrer for 180 min. at 25-30°C. The experiment was exercised at pH of 5, 7 and 9. Filtered the solution using Buckner funnel to get clear solution. Analysed filtrate sample for atomic absorption spectroscopy (AAS) and results are summarized in table6: -

S. No.	Solution Status	Heavy metal ions	Initial Heavy metal ions concentration (ppm)	Adsorbent	Sample quantity & Adsorbent Dose (g)	pH & Temperature (°C)	Contact Time (min)	Heavy metal ions concentration after treatment (ppm)	Removal %age
1.	Industrial Effluent	Cu	780	SBSA	100 & 1.0	5 & 25-30	180	51	93.5
				SBNA	100 & 1.0	5 & 25-30	180	57	92.7
				SBPA/SBOPA	100 & 1.0	5 & 25-30	180	51	93.5
2.	Industrial Effluent	Cu	780	SBSA	100 & 1.0	7 & 25-30	180	86	89.0
				SBNA	100 & 1.0	7 & 25-30	180	88	88.7
				SBPA/SBOPA	100 & 1.0	7 & 25-30	180	91	88.3
3.	Industrial Effluent	Cu	780	SBSA	100 & 1.0	9 & 25-30	180	123	84.2
				SBNA	100 & 1.0	9 & 25-30	180	116	85.1
				SBPA/SBOPA	100 & 1.0	9 & 25-30	180	112	85.6

Table6: Summarizes the removal/elimination of copper metal ions from the industrial effluent using SBSA, SBNA and SBPA/SBOPA at different pH

Adsorption Analysis

Effects of optimization conditions for adsorption

The impact of experimental variable pH on adsorption of heavy metals by the treated sugarcane bagasse were investigated. The impact of pH was analyzed at various levels at 5, 7 and 9 by adjusting the stock solution using 0.1N acetic acid and 0.1N ammonia solutions. The impact of pH was executed at 5,7 and 9. The adsorption experiments were conducted by stirring of 1.0 g of treated sugarcane bagasse with 100 g of stock solution contained in 250 ml conical flask. After equilibrium was established, the samples were removed by filtration using filter paper and Buckner funnel. The heavy metal concentration in the filtrate was quantified using Atomic Absorption Spectrometry (AAS). The elimination efficiency and the amount of metals adsorbed were calculated using the following Equations (1) and (2) respectively [17].

$$\text{Metal Elimination Efficiency} = \frac{C_i - C_f}{C_i} \times 100 \quad \ldots\ldots\ldots\ldots \quad (1)$$

$$\text{Amount of metal ion adsorbed (mg/g)} = \left(\frac{C_i - C_f}{M}\right) \times V \quad \ldots\ldots\ldots\ldots.. \quad (2)$$

Here, C_i denotes the starting concentration of the metal ions, whereas C_f refers to their concentration after the process (mg/g). The symbol M indicates the mass of the adsorbent in grams, and V represents the volume of the metal ion solution in litres.

Equilibrium adsorption isotherm models

The experimental results were interpreted using both Langmuir and Freundlich isotherm models. These both models assist in characterization of adsorbent's surface properties and estimation for maximum capacity of adsorption.

Langmuir isotherm model:

Langmuir isotherm is based on the basic assumptions that adsorption takes place on a homogeneous surface, i.e., monolayer adsorption takes place, and each adsorption site will grasp only one metal ion at a time [18,19]. The Langmuir isotherm in the linearized form is given below as Equation (3):

$$\frac{C_e}{C_q} = \frac{1}{K_L q_{max.}} + \frac{Ce}{q_{max.}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

In this context, C_e indicates the equilibrium concentration of metal ions in mg L^{-1}, while C_q represents the quantity of ions adsorbed per gram of adsorbent (mg/g). The term q_{max} refers to the maximum adsorption capacity corresponding to monolayer coverage, and K_L denotes the Langmuir constant associated with adsorption affinity.

The experimental results were analyzed by fitting them to the above equation through a plot of C_e/q_e versus C_e. From the linear relationship obtained, q_{max} and K_L were calculated using the slope and intercept, respectively. The feasibility of the adsorption process was further assessed using the separation factor, R_L equ. (4) which provides insight into the nature of the sorption mechanism [19].

$$R_L = \frac{1}{1 + K_L C_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where C_0 = the initial concentration of the metal ions (mg/L)

K_L Langmuir constant

Within the Langmuir isotherm framework, the nature of adsorption can be assessed using the dimensionless separation factor (R_L), which depends on the Langmuir constant (K_L) and the initial concentration of the metal ions (C_0).

- Values of R_L between 0 and 1 indicate favorable adsorption.
- An R_L value greater than 1 suggests that the adsorption process is unfavorable.
- When R_L equals 1, the adsorption behavior is linear, reflecting lower efficiency.
- An R_L value of 0 signifies irreversible adsorption.

III. Conclusion:

This investigation evaluates the potential of anion-treated sugarcane bagasse as an adsorbent for the removal of heavy metal ions from untreated industrial effluent. The highest copper ion removal was obtained under optimal conditions of pH 5.0, temperature between 25–30 °C, contact time of 180 minutes, and an adsorbent dose of 1.0 g. The adsorption efficiencies achieved were 93.5%, 92.7%, and 93.5% for sugarcane bagasse impregnated with sulphuric acid, nitric acid and ortho-phosphoric acid respectively. The equilibrium data were best represented by the Freundlich isotherm model, indicating heterogeneous adsorption, while the adsorption kinetics were consistent with a pseudo-second-order model. The maximum adsorption capacities for Cu (II) were determined as 72.8 mg/g, 72.3 mg/g, and 72.8 mg/g for sulphuric acid, nitric acid- and phosphoric acid impregnated-treated samples, respectively. These results confirm that anionic impregnated / impregnated sugarcane bagasse can be utilized as a cost-effective and efficient material for removing heavy metals from wastewater/industrial effluent.

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