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Comparative Adsorption of Lead and Cadmium from Wastewater onto Sugarcane Bagasse and Rice Husk Activated Carbons

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ABSTRACT

The discharge of various agricultural wastes into the environment causes environmental pollution that requires attention. Sugarcane bagasse (SBAC) and rice husk (RSAC) activated carbons were produced by thermal and chemical methods. The sugarcane bagasse and rice husk were both carbonized at temperatures of 300 and 350 °C at heating rate of 10 °C/min for 1 hour, after which chemical activation was carried out with 1M tetraoxophosphate (V) acid (H_3PO_4) at a mixing ratio of 2:1 (2 ml of H_3PO_4 to 1 g of SBAC and RSAC). In addition, batch adsorption experiment was carried out and the result showed that the adsorption of lead (Pb) onto SBAC and RSAC 300 recorded mean adsorption capacities and removal efficiencies of 15.2730 mg/g and 99.293% and 15.1828 mg/g and 98.656%, respectively. The result implied that the SBAC recorded higher adsorption capacity and removal efficiency than RSAC, which were statistically significant at 95% confidence level. Similarly, the batch adsorption of cadmium (Cd) onto SBAC and RSAC 300 showed that the mean adsorption capacity and removal efficiency of 6.3873 mg/g and 99.985% and 6.3853 mg/g and 99.943%, respectively, which implied that SBAC recorded higher adsorption capacity and removal efficiency than RSAC which was statistically at 95% confidence level but that of the RSAC was not statistically significant. It was therefore concluded that both the SBAC and RSAC were good adsorbent for the adsorptions of Pb and Cd from wastewater but the SBAC was more efficient than RSAC.

1. INTRODUCTION

Nigeria is ranked amongst the larger producers of sugarcane and rice in the world and it has been estimated that the Nigeria produced about 1.4 million tons of sugarcane; while the amount of paddy rice produced was estimated at 6.07 million tons (World Data Atlas, 2016). Sugarcane bagasse is the solid residue left after the removal of juice extract from the sugarcane, while rice husk is the residue left after processing of paddy rice (Mohammad, 2015; Adamu and Ahmadu, 2015). On this note, the quantities of sugarcane bagasse and rice husk generated in Nigeria are very alarming which in turn could lead to environmental pollution. This prompts the need to subject the sugarcane bagasse and rice husk to important applications that would help in reducing the quantities present in the environment, which was the justification behind carrying out this research.

Wastewater is usually released by industries, commercial areas, farms and homes after utilization for various purposes. The compositions of wastewater rely heavily on the application which the water was subjected to (Sovattei *et al.,* 2013).

Lead and cadmium uptake by human beings can result to tremendous health challenges which include kidneys malfunction, reproductive system disorder, liver problem and high blood pressure (Aliyah, 2012; Lata and Samadder, 2014).

Despite the availability of several techniques (ion-exchange, ultra-filtration, membrane filtration and reverse osmosis) for removal of heavy metals in wastewater, adsorption onto activated carbon is more preferred to due to ease of operation and maintenance as well as less cost of application (Bello *et al.,* 2014). In addition, due to the high cost of commercial activated carbon, researches have now been focused on the use of agricultural waste in the production of activated carbon. This goes a long way in reducing the environmental pollution that could occur due the presence of such agricultural wastes in the environment, hence the justification for this work.

The aim of the research is to produce activated carbons from sugarcane bagasse and rice husk with the view to comparing their respective efficiencies on the adsorptions of lead and cadmium from wastewater in order to determine more effective one, in terms of lead and cadmium adsorptions.

2. MATERIALS AND METHODS

2.1. Materials

The materials used in this work include 250 ml flask, 50 ml, 100 ml and 1000 ml measuring cylinders, 25 ml Pipette, electronic weighing balance (Mettler P160N), Oven (Griffin and George limited, serial no: 0514040410), Desiccator, retort stand, pH meter (pocket size, Hanna Instrument), electric furnace (Nabertherm, 30-3000ºC), centrifuge machine (Gallenramp Junoir), magnetic stirrer (79-1 stirrer), carbon - sulphur analyzer (CSA 996, Shangdong), atomic absorption spectrophotometer (AA 6800, Shimadzu), distilled and de-ionized water, 0.1M sodium hydroxide (NaOH) solution, 0.1M hydrochloric acid (HCl) solution and 1M tetraoxophosphate (V) acid (H_3PO_4).

2.2. Methods

2.2.1. Collection of sugarcane bagasse and rice husk

The sugarcane bagasse and rice husk were collected at Gaskiya Road and Zaria City market, respectively in Zaria Local Government Area of Kaduna State.

2.2.2. Production of sugarcane bagasse and rice husk activated carbons

The sugarcane bagasse and rice husk were washed with tap water, followed by distilled and then placed in the electrical oven, and dried over night at 100 ºC (Gaikwad and Mane, 2013; Mohd Adib *et al.,* 2014). They were ground and sieved through standard sieve test (0.6 mm) and then carbonized at 300 and 350 ºC each in an electrical furnace at the heating rate of 10 °C/min for 1 hour. They were designated as SBAC 300, SBAC 350, RSAC 300 and RSAC 350. The SBAC 300, SBAC 350, RSAC 300 and RSAC 350 were impregnated with 1M H_3PO_4 at the mixing ratio of 2:1 (2 ml of H_3PO_4 to 1 g of SBAC and RSAC) and stirred continuously for 3 hours (Singh and Srivastava, 2001; Pradhan, 2011). They were then filtered through a filter paper and washed thoroughly with distilled water to remove excess acid until the pH was 7. They were placed into the oven and dried at a temperature of 100 °C for 4 hours.

2.2.3. Preparation of lead (Pb) and cadmium (Cd) solutions

In order to produce 100 mg/l of Pb and Cd solutions, 0.1599 g of $Pb(NO_3)_2$ and 0.2774 g of $Cd(NO_3)_2.4H_2O$ were separately dissolved in 10 ml of 0.1M HNO_3 in 1000 ml volumetric flask and de-ionized water was added up to the 1000 ml mark to make 100 mg/l of Pb and Cd solutions. In addition, 25 and 60 mg/l of Cd and Pb were prepared by adding 75 and 40 ml of de-ionized water to the 25 and 60 ml of 100 mg/l Cd and Pb solutions.

2.2.4. Batch adsorption experiments

The batch adsorption of Pb onto SBAC and RSAC was carried out by placing 0.2 g each of SBAC and RSAC into 250 ml flask containing 60 mg/l of Pb solution and agitated for 10 mins at ambient temperature. Similarly, 1.0 g of SBAC and RSAC each were placed into 250 ml flask containing 25 mg/l Cd solution and agitated for 30 mins. The residual concentrations of Pb and Cd were measured using Atomic Absorption Spectrophotometer. The adsorption capacity at equilibrium (q_e) and removal efficiency ($R.E$) were determined using Equations (1) and (2)

$$q_e = \left(\frac{c_o - c_e}{w}\right) \times v \tag{1}$$

$$R.E = \left(\frac{c_o - c_e}{c_o}\right) \times 100\% \tag{2}$$

Where c_o is the initial concentration of Pb/Cd, c_e is the equilibrium concentration of Pb/Cd, w is the adsorbent dosage and v is the volume of the solution.

3. RESULTS AND DISCUSSION

The carbon contents of the sugarcane bagasse and rice husk obtained using carbon-sulphur analyzer (CSA 996, Shangdong) are provided in Table 1. The Table shows that sugarcane bagasse had carbon content of 63.04% while that of rice husk was 47.17%, which implied that the sugarcane bagasse had higher carbon content than rice husk. However, from the results, both sugarcane bagasse and rice husk were carbonaceous materials that could be used to produce activated carbons (Aragaw, 2016; Salihi *et al.,* 2017). In a study carried out by Wannapeera *et al.* (2008), the carbon content of the rice husk considered was found to be 48.9%, which was slightly higher than the 47.17% obtained in this research. In addition, the carbon of raw coconut shell obtained by Mohd Iqbaldin *et al.,* (2013) was 49.62%, which was lower than sugarcane bagasse but higher than that of rice husk utilized in this work.

Table 1: Carbon contents of raw sugarcane bagasse and rice husk

Sample identity	Carbon content (%)
Sugarcane bagasse	63.04
Rice husk	47.17

Table 2 shows the comparison of the removal efficiency and adsorption capacity of Pb onto SBAC 300 and RSAC 300. From the Table, the SBAC 300 recorded adsorption capacities of 29.9437, 9.9781 and 5.8971 mg/g at the adsorbent dosages of 0.2, 0.6 and 1.0 g, respectively with the corresponding removal efficiencies of 99.812, 99.781 and 98.286%. Similarly, the RSAC 300 recorded adsorption capacities of 29.7983, 9.8795 and 5.8707 mg/g at the adsorbent dosages of 0.2, 0.6 and 1.0 g, respectively; with the relative removal efficiencies of 99.328, 98.795 and 97.844%. The results indicated that at the same adsorbent dosages, the SBAC 300 recorded higher adsorption capacity and removal efficiency than RSAC 300 under the same batch adsorption conditions, which were both was statistically significant at 95% confidence level (Tables 3 and 4). However, the higher adsorption capacities and removal efficiencies recorded by the SBAC could be attributed to the higher carbon content possessed by the sugarcane bagasse than rice husk as indicated in Table 1 (Salihi *et al.,* 2017).

Table 2: Comparison of adsorption capacity and removal efficiency of Pb onto SBAC 300 and RSAC 300 (C_o=60mg/l)

	w (g)	Ce (mg/l)	qe (mg/g)	R.E (%)		Ce (mg/l)	qe (mg/g)	R.E (%)
SBAC	0.2	0.1126	29.9437	99.812	RSAC	0.4034	29.7983	99.328
	0.6	0.1313	9.9781	99.781		0.7233	9.8795	98.795
	1.0	1.0287	5.8971	98.286		1.2935	5.8707	97.844
	Mean		15.2730	99.293			15.1828	98.656

Table 3: Two way ANOVA for adsorption capacity of Pb onto SBAC 300 and RSAC 300

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	659.6223	2	329.8112	183533.6	5.45E-06	19
Columns	0.012186	1	0.012186	6.781292	0.121226	18.51282
Error	0.003594	2	0.001797			
Total	659.6381	5				

Table 4: Two way ANOVA for removal efficiency of Pb onto SBAC 300 and RSAC 300

Source of Variation	SS	Df	MS	F	P-value	F crit
Rows	2.560185	2	1.280093	27.94433	0.034549	19
Columns	0.609291	1	0.609291	13.30077	0.067644	18.51282
Error	0.091617	2	0.045809			
Total	3.261093	5				

From Table 5, the SBAC 350 had adsorption capacities of 29.9662, 9.9724 and 5.8932 mg/g at the dosages of 0.2, 0.6 and 1.0 g, respectively, with the relative removal efficiencies of 99.887, 99.724 and 99.720%. Similarly, the RSAC 350 recorded adsorption capacities of 29.8937, 9.9618 and 5.9751 mg/g at the adsorbent dosages of 0.2, 0.6 and 1.0 g, respectively, with the corresponding removal efficiencies of 99.646, 99.618 and 99.585%. The results indicated that the SBAC 350 recorded higher adsorption capacity and removal efficiency than RSAC 350 under the same batch adsorption conditions. In addition, the higher adsorption capacity recorded by SBAC was statistically significant at 95% confidence level, while that of removal efficiency was not statistically significant (Tables 6 and 7).

Table 5: Comparison of adsorption capacity and removal efficiency of Pb onto SBAC 350 and RSAC 350 (C_o=60mg/l)

	w (g)	Ce (mg/l)	qe (mg/g)	R.E (%)		Ce (mg/l)	qe (mg/g)	R.E (%)
	0.2	0.0677	29.9662	99.887		0.2126	29.8937	99.646
SBAC	0.6	0.1657	9.9724	99.724	RSAC	0.2293	9.9618	99.618
	1.0	0.1678	5.9832	99.720		0.2491	5.9751	99.585
	Mean		15.3073	99.777			15.2769	99.616

In addition, it can also be observed that both the SBAC 350 and RSAC 350 recorded higher adsorption capacity and removal efficiency in Table 5 than SBAC 300 and RSAC 300 in Table 2, which could be attributed to the increased in the carbonization temperature from 300 to 350°C. The increased in the carbonization temperature enabled the enhancement of pores, which in turn improved the adsorptions of lead and cadmium from the aqueous solution. This observation agreed with those of Mohammad (2015).

Table 6: Two way ANOVA for adsorption capacity of Pb onto SBAC 350 and RSAC 350

Source of Variation	SS	Df	MS	F	P-value	F crit
Rows	658.7066	2	329.3533	494944.4	2.02E-06	19
Columns	0.001386	1	0.001386	2.083209	0.285725	18.51282
Error	0.001331	2	0.000665			
Total	658.7093	5				

Table 7: Two way ANOVA for removal efficiency Pb onto SBAC 350 and RSAC 350

Source of Variation	SS	Df	MS	F	P-value	F crit
Rows	0.014972	2	0.007486	2.964623	0.252231	19
Columns	0.038721	1	0.038721	15.33391	0.059458	18.51282
Error	0.00505	2	0.002525			
Total	0.058743	5				

Table 8 shows the adsorption capacity and removal efficiency of Cd onto SBAC 300 and RSAC 300. From the Table, the SBAC 300 recorded adsorption capacities of 12.4955, 4.1664 and 2.4999 mg/g at the dosages of 0.2, 0.6 and 1.0 g, respectively, with the corresponding removal efficiencies of 99.964, 99.994 and 99.996%. Similarly, the RSAC 300 recorded adsorption capacities of 12.4930, 4.1642 and 2.4986 mg/g at adsorbent dosages of 0.2, 0.6 and 1.0 g, respectively, with the corresponding removal efficiency of 99.994, 99.941 and 99.943% under the same batch experimental conditions.

Table 8: Comparison of adsorption capacity and removal efficiency of SB 300- Cd and RS 300- Cd (C_o=25mg/l)

	w (g)	Ce (mg/l)	qe (mg/g)	R.E (%)		Ce (mg/l)	qe (mg/g)	R.E (%)
SBAC	0.2	0.0090	12.4955	99.964	RSAC	0.0141	12.4930	99.944
	0.6	0.0016	4.1664	99.994		0.0147	4.1642	99.941
	1.0	0.0009	2.4999	99.996		0.0143	2.4986	99.943
	Mean		6.3873	99.985			6.3853	99.943

The results showed that at the same batch conditions, SBAC 300 recorded higher adsorption capacity and removal efficiency than RSAC 300. In addition, the higher adsorption capacity recorded by SBAC 300 was statistically significant at 95% confidence level, while that of removal efficiency was not statistically significant (Tables 9 and 10).

Table 9: Two way ANOVA for adsorption capacity of Cd onto SBAC 300 and RSAC 300

Source of Variation	SS	Df	MS	F	P-value	F crit
Rows	114.6981	2	57.34905	2.94E+08	3.4E-09	19
Columns	6E-06	1	6E-06	30.76923	0.030997	18.51282
Error	3.9E-07	2	1.95E-07			
Total	114.6981	5				

Table 10: Two way ANOVA for removal efficiency of Cd onto SBAC 300 and RSAC 300

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.000284	2	0.000142	0.783287	0.560762	19
Columns	0.002646	1	0.002646	14.57851	0.062257	18.51282
Error	0.000363	2	0.000182			
Total	0.003293	5				

In Table 11, it can be observed that, the SBAC 350 recorded adsorption capacities of 12.4934, 4.1663 and 2.4998 mg/g at the adsorbent dosages of 0.2, 0.6 and 1.0 g, respectively, with the corresponding removal efficiencies of 99.947, 99.990 and 99.992%. Similarly, the RSAC 350 recorded adsorption capacities of 12.4882, 4.1640 and 2.4984 mg/g at dosages of 0.2, 0.6 and 1.0 g, respectively with the relative removal efficiencies of 99.905, 99.936 and 99.937%. In addition, the result further indicated that at the same batch conditions, the SBAC 350ºC recorded higher adsorption capacity and removal efficiency than the RSAC 350 ºC, which were both statistically significant at 95% confidence level (Tables 12 and 13).

Table 11: Comparison of adsorption capacity and removal efficiency of Cd onto SB 350 and RS 350 (C_o=25mg/l)

	w (g)	Ce (mg/l)	qe (mg/g)	R.E (%)		Ce (mg/l)	qe (mg/g)	R.E (%)
	0.2	0.0133	12.4934	99.947		0.0237	12.4882	99.905
SBAC	0.6	0.0024	4.1663	99.990	RSAC	0.0161	4.1640	99.936
	1.0	0.0020	2.4998	99.992		0.0157	2.4984	99.937
	Mean		6.3865	99.976			6.3835	99.926

Table 12: Two way ANOVA for adsorption capacity of Cd onto SBAC 350 and RSAC 350

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	114.6175	2	57.30875	29066144	3.44E-08	19
Columns	1.32E-05	1	1.32E-05	6.695689	0.122503	18.51282
Error	3.94E-06	2	1.97E-06			
Total	114.6175	5				

Table 13: Two way ANOVA for removal efficiency of Cd onto SBAC 350 and RSAC 350

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.001902	2	0.000951	36.35032	0.026774	19
Columns	0.0038	1	0.0038	145.2293	0.006815	18.51282
Error	5.23E-05	2	2.62E-05			
Total	0.005755	5				

The binary adsorption of the Cd and Pb onto SBAC and RSAC are presented in Tables 14 and 15, respectively. From Table 14, it can be observed that, at the same adsorbent dosage and initial concentration of: 0.1 g and 25 mg/l, the binary adsorptions of Cd and Pb onto SBAC were 24.9981 and 24.5641 mg/g, respectively with the corresponding removal efficiencies of 99.992 and 98.256%. Furthermore, when the adsorbent dosage increased to 0.2 g, the binary adsorptions of Cd and Pb onto SBAC achieved were 12.4995 and 12.0806 mg/g, respectively with the relative removal efficiencies of 99.996 and 96.645%. The results indicated that in the same aqueous solution containing Cd and Pb under the same concentrations, SBAC removed more Cd than Pb. In addition, the increase in the adsorbent dosage from 0.1 to 0.2 g, led to the removal of more Cd from 99.992 to 99.996%, while that of Pb declined from 98.256 to 96.645%.

Similarly, in the single mode adsorption observed earlier, the lead adsorption was higher than the cadmium, which could be attributed to the fact that the solubility of cadmium in aqueous solution was higher than that of lead (Grassi *et al.,* 2012). Meanwhile, in another study carried out by El Said *et al.* (2012), it was found that in binary solution containing cadmium and mercury, the rice husk ash adsorbed cadmium more than mercury. This observation was also reported by Daniel *et al.* (2014).

Table 14: Selective adsorptions of Cd and Pb onto SBAC

			Cd			Pb	
w (g)	Co (mg/l)	Ce (mg/l)	Qe (mg/g)	R.E (%)	Ce (mg/l)	Qe (mg/g)	R.E (%)
0.1	25	0.0019	24.9981	99.992	0.4359	24.5641	98.256
0.2	25	0.0010	12.4995	99.996	0.8388	12.0806	96.645

In Table 15, at the same adsorbent dosage and initial concentration of: 0.1 g and 25 mg/l, the binary adsorptions of Cd and Pb onto RSAC were 24.9979 and 24.5375 mg/g, respectively with the corresponding removal efficiencies of 99.992 and 98.150%. Furthermore, when the adsorbent dosage increased to 0.2 g, the binary adsorptions of Cd and Pb onto RSAC were 12.4995 and 12.0806 mg/g, respectively with the corresponding removal efficiencies of 99.996 and 97.564%. The result indicated that in the same aqueous solution containing Cd and Pb at the same concentrations, the RSAC removed Cd more than the Pb. Meanwhile, the increase in the adsorbent dosage from 0.1 to 0.2 g led to more removal of Cd from 99.992 to 99.996%, while that of Pb reduced from 98.150 to 97.564% suggesting antagonistic relationship.

Table 15: Selective adsorptions of Cd and Pb onto RSAC

			Cd			Pb	
w (g)	Co (mg/l)	Ce (mg/l)	Qe (mg/g)	R.E (%)	Ce (mg/l)	Qe (mg/g)	R.E (%)
0.1	25	0.0021	24.9979	99.992	0.4625	24.5375	98.150
0.2	25	0.0011	12.4995	99.996	0.6091	12.1954	97.564

4. CONCLUSION

The sugarcane bagasse and rice husk activated carbons were successfully produced and utilized for the adsorptions of lead and cadmium from wastewater. It can be concluded that, at lead concentration of 60 mg/l, the SBAC and RSAC 300 recorded adsorption capacities and removal efficiencies of 15.2730 mg/g and 99.293% and 15.1828 mg/g and 98.656%, respectively which implied that the SBAC adsorbed more Pb from the aqueous solution than the RSAC which was statistically significant at 95% confidence level. Similarly, at cadmium concentration of 25 mg/l, the SBAC and RSAC 300 recorded adsorption capacities and removal efficiencies of 6.3873 mg/g and 99.985% and 6.3853 mg/g and 99.943%, respectively but only that of adsorption capacity was statistically significant at 95% confidence level which implied that the SBAC was more effective than RSAC. In addition, in the same aqueous solution containing lead and cadmium, both the SBAC and RSAC adsorbed more cadmium than the lead.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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