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Synthesis and Physicochemical Characterization of Bio based Adsorbents from Sugarcane Bagasse using Microwave Assisted Irradiation Method

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Abstract:- Three biosorbents, SBNa (bagasse modified with sodium hydroxide), SBW (sugarcane bagasse modified with distilled water) and SBU (untreated sugarcane bagasse) were prepared from sugarcane stalks using microwave irradiation assisted method. The biosorbents were further characterized using physicochemical procedures. Experimental results obtained from characterization processes how that SBN a falls into the alkaline pH range (9.1) making it a very promising biosorbent for uptake of cationic species when compared with SWB (pH = 7.7) and SBU (pH = 7.1). All three biosorbents showed bulk densities lower than the minimum requirement (0.25gcm^{-3}) for application in the removal of pollutants from waste water. Surface area studies also show that SBNa has the largest surface area (74.2 m^2/g), SBW (69.4 m^2/g) and SBU (34.44 m^2/g). A comparison of surface area of SBNa, SBW, SBU with that of similar biosorbents reveals that SBNa has the higher surface area. Therefore, the results obtained from this study can serve as a validation that all the three synthesized biosorbents could be good adsorbents for removal of cationic species from aqueous systems.

Keywords:- *Agrowastes, characterization, physicochemical, bulk density, surface area, pH, Sugarcane bagasse, Sodiumhydroxide.*

I. INTRODUCTION

Increasing environmental awareness in today's world is driving the search for new techniques capable of treating polluted wastewaters at relatively low-cost.The search for new technologies the sequestration of toxic metals from wastewaters has focused attention to biosorption due to evidence of high binding capacities of various biological materials (Ramachandra *et al.,* 2005).

Biosorption is a subdivision of adsorption where the adsorbent is a biological matrix and can be considered as a technique for the removal of pollutants through a material of biological origin independent of their metabolic activity (Gadd, 2009). Today, biosorption is considered a simple, economical and environmentally friendly process that is used as an attractive substitute for eliminating pollutants. The biosorption process has advantages over conventional treatment methods. Some of such include; low cost, high efficiency, minimization of chemical utilization and biosorbent regeneration capacity(Fomina and Gadd, 2014).

The biosorption process involves a solid phase which is the adsorbent (biological material) and a liquid phase (solvent, normally water) containing a dissolved species to be sorbed. Due to the high affinity, adsorbate species are attracted and bound to the adsorbent via different mechanisms. The process continues until equilibrium is established between the amount of solid-bound adsorbate species and adsorbate portion remaining in the solution. The degree of adsorbent affinity for the adsorbate determines its distribution between the solid and liquid phases (Ramachandra *et al.,* 2005).

Very many biosorption studies have been carried out in the last decade, and advances in this field have reinforced the interest in this technique to solve environmental pollution problems. Existing information on biosorption is ample due to the large number of experimental reports that are published, all in a bid to test the viability of certain materials as biosorbents or to develop more complex hybrid materials that could be more efficient. Biosorbents can be obtained from waste biomaterials generated from agriculture and food industries; this makes biosorption a pocket friendly alternative treatment method.

A large variety of low-cost adsorbents have been investigated for their ability to remove color from wastewater such as peat, bentonite, fly ash, steel-plant slag, Chinaclay, maize cob, wood and silica. However, these low-cost adsorbents have relatively low adsorption capacities thus, there isneed to inventnovel, economical, easily available, and highly effective adsorbents (Srinivasan and Viraraghavan, 2010).

Agricultural by-products, such as sugarcane bagasse, rice husk, coconut husk, sisal, and so on, have been studied as potential sorbent materials for removing contaminants from wastewater. Modern agricultural industries produce millions of tons of waste and by-productsyearly, and these could serve as potential precursors for development of effective biosorbents. These agro-industrial residues are a promising alternative to traditional adsorbents as they are cheap, readily available, highly sorptive, and easy to manipulate during the treatment process (Tran *et al.,* 2015). Besides, the potential use of several agricultural by-products as biosorbent can be linked to the functional groups that abound within their main constituents such as cellulose, hemicelluloses and lignin. These are polymeric structures with high content of hydroxyl and carboxyl groups, which have a strong influence in the adsorption capacity of different species extant in aqueous media (Sarker *et al.,* 2017).

Sugarcane bagasse (SB)can be described as one of the most available agro-industrial residues, especially in tropical regions (Sarker *et al.*, 2017). Brazil is the world's top producer of sugarcane (*Saccharum sp.*), followed by India, China and Bangladesh (Tabriz*et al.*, 2021). Sugarcane (SB), in nature or chemically modified, has been reported as a potential renewable sorbent for wastewater treatment (Sarker *et al.*, 2017). Sugar cane bagasseis the major by-product from the sugar cane industry as such, it is one of the largest agriculture residues in the world as millions of tons of sugarcane bagasseis generated every year by the sugarcane agribusiness. The sugarcane industry is based mainly on the production of sugar and ethanol, which generates huge volumes of SB and sugarcane trash.

Sugarcane bagasse is the fibrous residue that remains after the crushing and the extraction of juice from sugarcane stalks and is one of the most abundant lignocellulosic agro-industrial residues (Paixao *et al.*, 2014). Sugarcane bagasse is composed of several useful components, including cellulose (48%), hemicelluloses (33%), lignin (23%), ash (5%), and a small number of extractives (Mahmud & Anannya(2021). Lignocellulose matter provides a strong attractive force for the binding of pollutant ions because of its numerous and varied functional groups (Okoro and Okoro 2011). The hydroxyl groups are the most abundant reactive sites in this biopolymer and high content of cellulose in the SB biomass favors its hydrophilicity, which in turn improves its interaction with cationic species in aqueous media (Sarker *et al.*, 2017). Some of the predominate functional groups that act as adsorptive sites in sugar cane bagasse including; –OH, -COOH, $-NH_2$, $-CONH_2$, $-SH_2$ and $–OCH_2$ (Iwuozor, *et al.*, 2022). These sites enable the biosorbents to attract and bind pollutant ions, either by replacing them with hydrogen ions (ion exchange), adsorption, or by the donation of electron pairs (complexation) (De Moraes Rocha *et al.*, 2015). The presence of such unique binding sites and its high levels (10.3%) of silica make sugarcane bagasse and its derivatives particularly effective at removing contaminants (Boni *et al.*, 2016). Furthermore, its biological biopolymers, such as cellulose and lignin, can provide the developed adsorbent materials with additional properties (Ngah and Hanafiah, 2008).

Although, the utilization of sugarcane bagasse as a low-cost adsorbent has introduced a new alternative forwastewater treatment procedures. It has some shortcomings too. A report made available by Hadi in 2012, suggests that being a waste from the sugar industry,sugarcane bagasse must be cleaned and pretreated in order to remove contaminants from its surface before it can be used as a sorbent. In some cases, raw sugarcane bagasse also required several modifications to improve its sorption potential (Raghuvanshi *et al.*, 2004).

Wide variety of plant materials like canola meal, moss, peat and water hyacinth havebeen tested for their efficiency in biosorption processes (Volesky, 2003). Apple residue, banana pith, corn cobs, coconut husks, sugarcane bagasse, olive mill solid residue, rice husk, wheat straw, peanut skins, spent grain, tea leaves and similar plant by-products, and activated carbon derived from the by-products of plants were also studied (Chojnacka, 2006).

Biosorbents are inactive non-living materials from biomass and cellular product such as cellulose and lignin that can be utilized in eliminating pollutants from water or any other solution. Biosorption of species occur when there is high attractive force between the biosorbent and such species. It may also be due to presence of functional groups like hydroxyl, carboxyl and amines among others (Wang and Chen, 2009). The type of functional groups on the adsorbents determines the adsorption selectivity for adsorbates.

In recent times there has been so much focus on the development of selective, high-performance and low cost biosorbents because practical applications of biological species(algae, bacteria, fungi, etc.) as adsorbents for sequestration of pollutants has been challenging. Characterization of biosorbents helps scientific investigators to understand the physical, chemical and mechanical properties of biosorbents because development and application of biosorbents is facilitated by their proper characterization (Sivashankar *et al.*, 2022). Therefore, this study is aimed at synthesizing biosorbents from sugar cane bagasse via chemical modification using microwave assisted irradiation procedure. And subsequent characterization of the synthesized materials using pH, bulk density and surface area measurements.

II. MATERIALS AND METHOD

A. *Collection and preparation of biosorbent*

Sugarcane stalks used for this experiment was harvested from a farm in Ogobiri community, Bayelsa state. The stalks were cut into small pieces and washed with distilled water to remove possiblecontaminants. The juice is then extracted and the bagasse is washed again with distilled water and sun dried to a constant weight. The sundried sugarcane bagasse is then milled into powder using a domestic bender, sieved to mesh size of 710mm and stored in an air-tight sample container for further use. The dried biomass is divided into three portions.

B. *Portion I,Unmodified Sugar cane bagasse*

This portion is left as it is and named unmodified sugar cane bagasse (SBU).

C. *Portion II: Modification of sugar cane bagasse using distilled water*

Unmodified sugar cane bagasse is modified using similar methods as reported in our previous work (Ebelegi *et al.*,2022). Wherein, 10 g of biomass (USB) was weighed and mixed with 160mL distilled water in a 250 mL beaker. The mixture is subjected to microwave irradiation for 5 minutes, allowed to cool at room temperature, filtered through a filter paper and washed with distilled water. The residue obtained oven dried for 24 hours at $60^{o}C$ and later sieved to particle size less than +10 micro meter. The resulting powder obtained is stored in an air-tight sample container labeled sugarcane bagasse treated with water (SBW).

D. Portion III: Modification of sugar cane bagasse using NaOH solution

Approximatey,10 g of U-SBis weighed and mixed with 100 mL sodium hydroxide solution (1.0M)in a 250 mL beaker.The mixture was placed in a microwave for 5 minutes, after which it is allowed to cool at room temperature and later washed with distilled water to remove excess sodium hydroxide. The treated biomass is then oven dried at 60°C for 24 hours. The dried sodium hydroxide treated biomass is crushed, sieved to particle size less than 710mm and stored in an air-tight sample container labeled (SBNa).

III. RESULTS AND DISCUSSION

A. pH dependence

One of the most important parameters in adsorption processes is the pH, since it affects, dissociation, hydrolysis, complexation, precipitation and other interactions between adsorbates and adsorbents (Ofomaja and Ho, 2007). Accordingly, pH affects the degree of ionization and activity of functional groups domiciled on the surfaces of biosorbents. Thus, at low pH surface active functional groups are largely associated with hydrogen ions [H^+] which disfavours the uptake of cationic species (Manirethan et al., 2018).Results obtained from pH measurements displayed in table 1 and figure 1 show that Na-SB falls into the alkaline pH (9.1) range making it a more promising biosorbent for uptake of cationic species while W-SB (7.7) and U-SB (7.1) possess relatively neutral pH values.

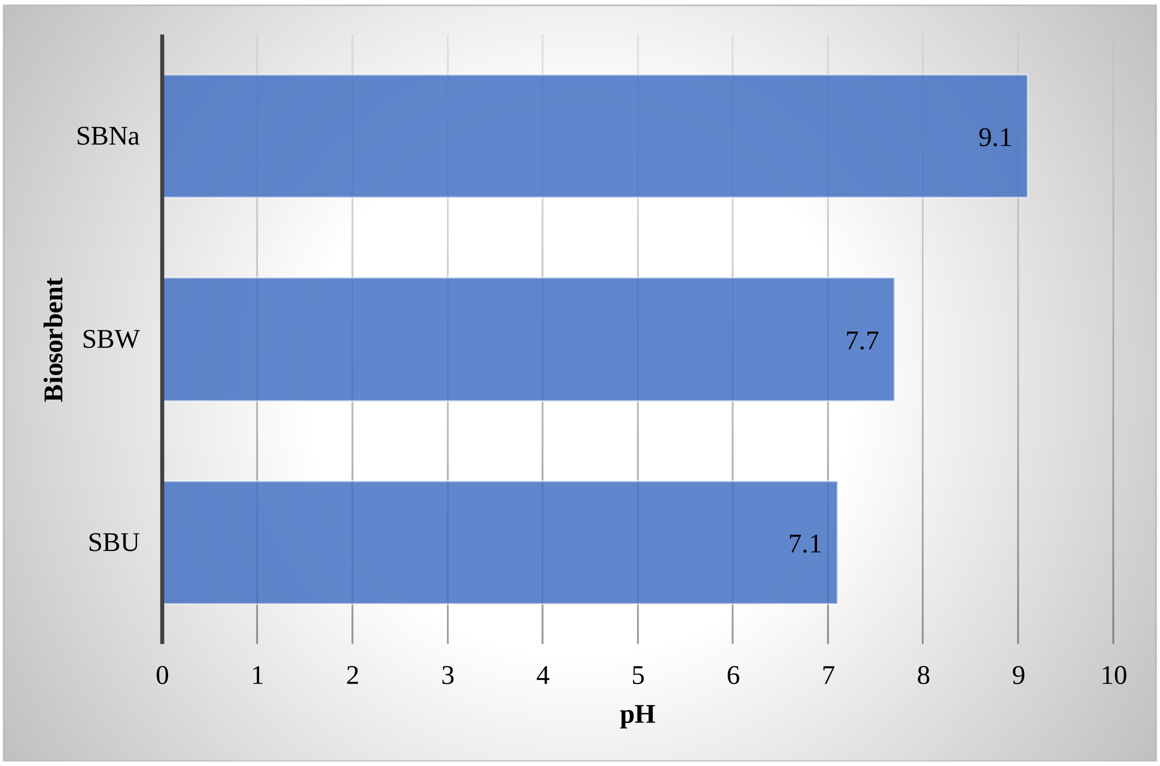

Fig. 1: pH values for biosorbents

B. Bulk density

Bulk density is the mass of bulk solid that occupies a unit volume of a bed, including the volume of all inter particle voids (Fitzpatrick et al., 2013). Surface area available for adsorption is often described as specific surface area and any increase in surface area of an adsorbent increases the adsorption capacity of the adsorbent (Ahmedna, M., Marshall, W.E. and Rao, R.M. (2000). These result shows that all bio-sorbents used in this study have bulk densities lower than the minimum requirement ($0.25gcm^{-3}$) for application in the sequestration of pollutants from waste water (Ibrahim and Mohammed, 2017).

Biosorbent	**Bulk density (g/cm^3)**
SBU	0.2363
SBW	0.1842
SBNa	0.0135

Table 1: Bulk Density

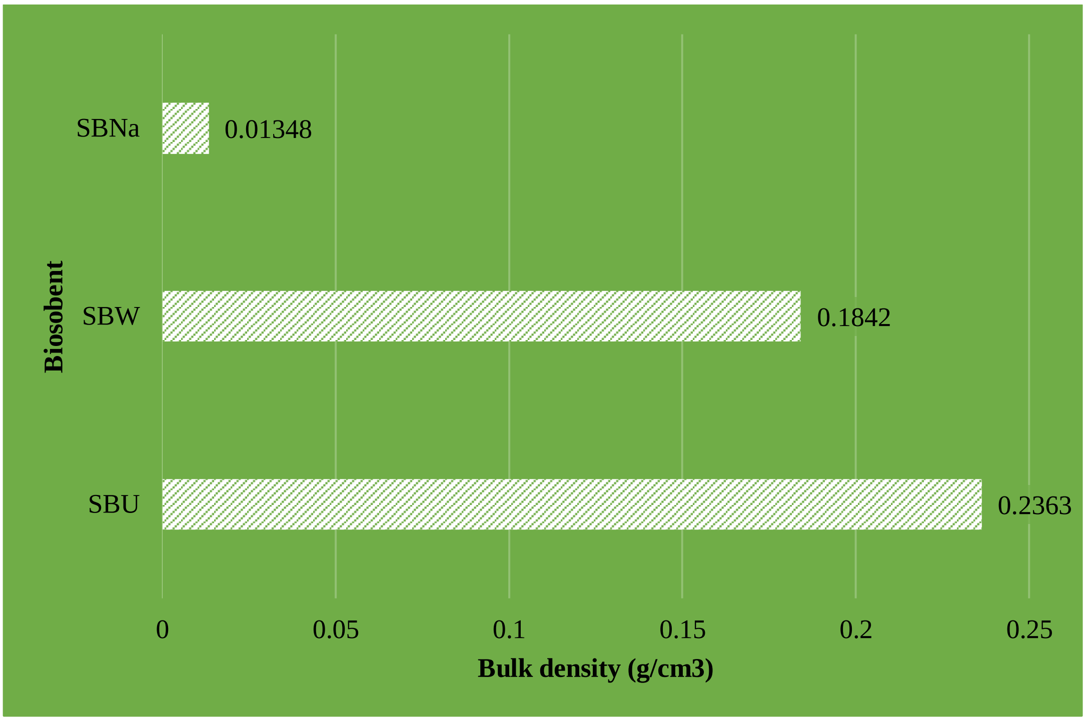

Fig. 2: Bulk density of biosorbents

C. *Surface area*

Specific surface area is a very important parameter in adsorption studies because it is often used in assessing the adsorption capacity of adsorbents. The surface area study evaluations shown in table 2 and figure 3 illustrates that SBNa has the largest surface area (74.2 m^2/g), SBW (69.4 m^2/g) and SBU (34.44 m^2/g). Recall that large surface area boosts adsorption capacities of adsorbents because a large surface area enables the adsorbent to have a higher contact with adsorbate molecules. Accordingly, SBNa should possess higher adsorption capacity than SBW and SBU.

Biosorbent	Surface area (m^2/g)
SBU	36.44
SBW	69.4
SBNa	74.2

Table 2: Surface Area

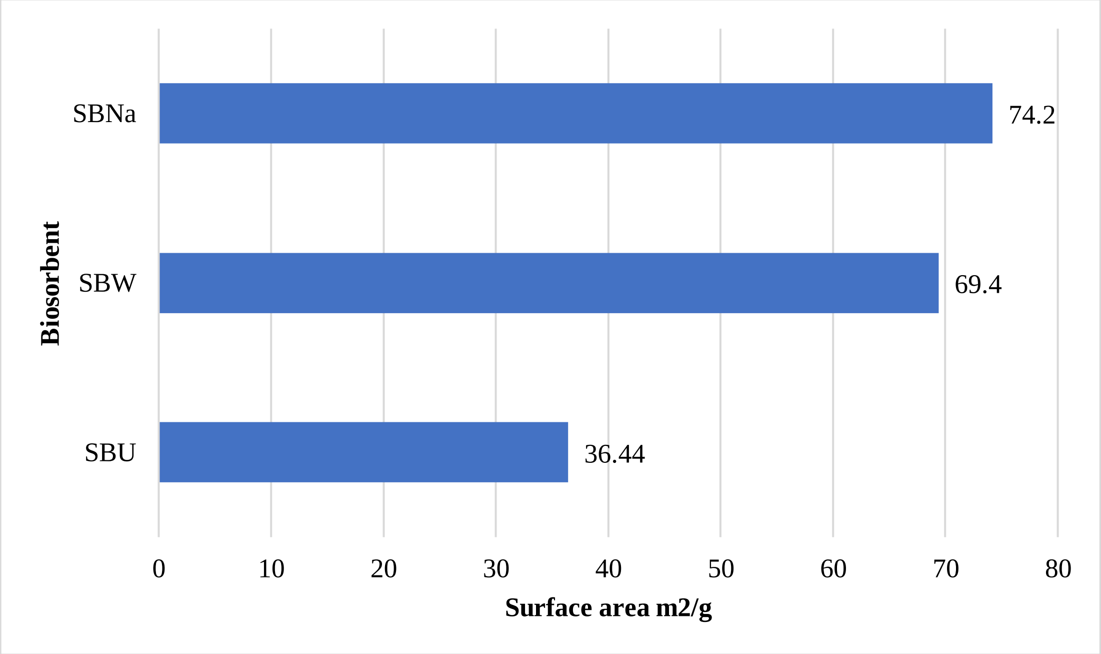

Fig. 3: Surface area of biosorbents

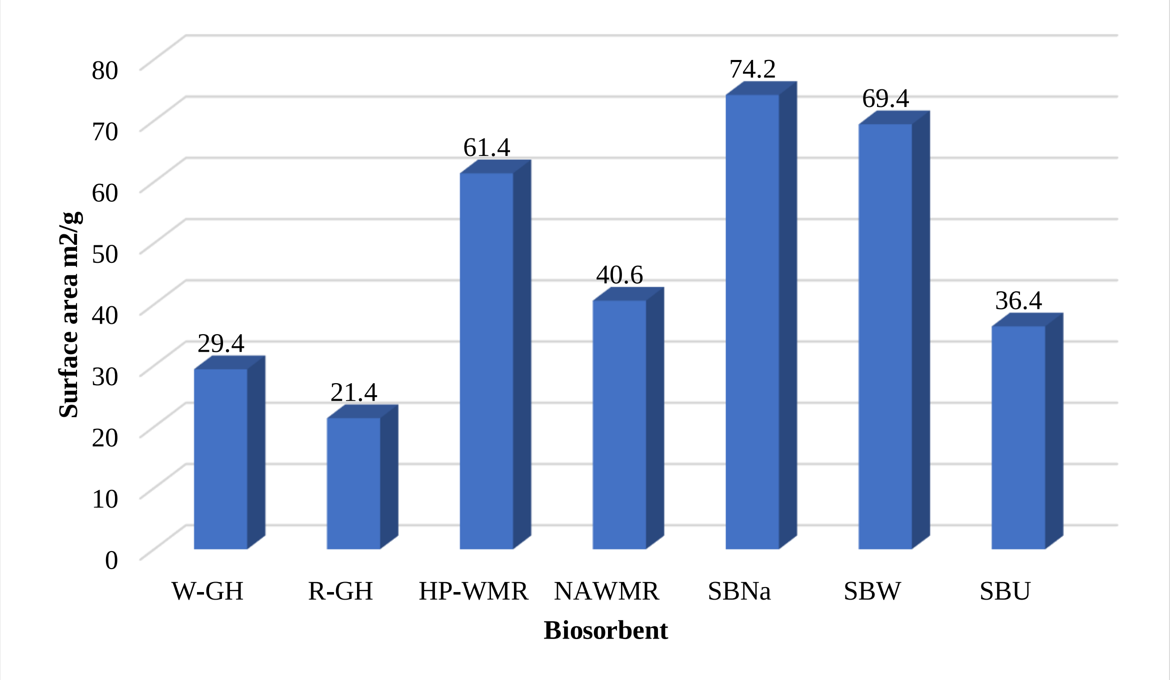

Fig. 4: A comparison of surface area of SBNa, SBW, SBU with that of similar biosorbents [W-GH, R-GH (Ebelegi *et al.*, 2023)., HP-WMR,NAWMR,DWMR (Ebelegi *et al.*, 2022)]

Figure 4 is an illustrative comparison of the surface area of biosorbents used in this study and that of similar biosorbents in our previous studies. The comparison reveals that SBNa has the highest surface area than what is obtained for similar biosorbents.

IV. CONCLUSION

Three biosorbents sugarcane; SBNa (bagasse modified with sodium hydroxide), SBW (sugarcane bagasse modified with distilled water) and SBU (untreated sugarcane bagasse) were prepared from sugarcane stalks using microwave irradiation assisted technique. The biosorbents were further characterized using physic chemical procedures. Experimental results obtained from characterization procedures show that SBNa falls into the alkaline range (pH= 9.1) making it a more promising biosorbent for uptake of cationic species while SBW (7.7) and SBU (7.1) possess relatively neutral pH values. All three biosorbents used exhibited bulk densities lower than the minimum requirement (0.25gcm^{-3}) for application in the sequestration of pollutants from waste water.

Surface area studies of the synthesized biosorbents also show that SBNa has the largest surface area (74.2 m^2/g), SBW (69.4 m^2/g) and SBU (34.44 m^2/g).And a comparison of surface area of SBNa, SBW, SBU with that of similar biosorbents reveals that SBNa has the highest surface area. Consequently, the result obtained from this study could serve as a confirmation that all the three synthesized biosorbents have the features of a good adsorbent.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this article.

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