



# INTERNATIONAL JOURNAL OF RESEARCH AND TECHNOPRENEURIAL INNOVATIONS (IJRTI)

ISSN: 3043-5722

Volume 2 Issue 1 (April 2025)

Central Instrument Laboratory, University of Port Harcourt, Nigeria

E-mail: [centralinstrumentlaboratory@uniport.edu.ng](mailto:centralinstrumentlaboratory@uniport.edu.ng)

Website: <http://cil.uniport.edu.ng/journal/>



## Potential Application of Hexadecyltrimethyl Ammonium Bromide Modified Bentonite as Adsorbent for the Removal of Triclosan from Aqueous Medium

Kelechi Emmanuel Onwuka<sup>1</sup>, Christopher Ugochukwu Aghalibe<sup>2</sup>, Okechukwu Chibuike Atasie<sup>3</sup>, Williams Chinonso Okafor<sup>4</sup>, Nnamdi Ekene Enenwa<sup>2</sup>

<sup>1</sup> Chemistry Research Unit, Department of Science Laboratory Technology, Federal Polytechnic, Ngodo-Isuochi, Abia State, Nigeria

<sup>2</sup> Department of Pure and Industrial Chemistry, Abia State University Uturu, Abia State, Nigeria. P.M.B. 2000

<sup>3</sup> Department of Biochemistry, Abia State University, Uturu, Abia State, Nigeria. P.M.B. 2000.

<sup>4</sup> Bioresource Development Center, National Biotechnology Development Agency, Lugbe Abuja, Nigeria

### Email address:

\*Corresponding author: [ke.onwuka@fpi.edu.ng](mailto:ke.onwuka@fpi.edu.ng)

### To cite this article:

Onwuka, K.E., Aghalibe, C.U., Atasie, O.C., Okafor, W.C. and Enenwa, N.E.

Potential Application of Hexadecyltrimethyl Ammonium Bromide Modified Bentonite as Adsorbent for the Removal of Triclosan from Aqueous Medium. *International Journal of Research and Technopreneurial Innovations*, 2025; 2(1):143-150

### Keywords:

Adsorption kinetics, Thermodynamics, Bentonite, Triclosan, Personal care products

### ABSTRACT

In this study, the adsorption efficiency of hexadecyltrimethyl ammonium bromide modified bentonite (Bt-HDTMA) was assessed as a potential adsorbent for effective removal of triclosan from aqueous solution. Batch adsorption test was performed by varying contact time and temperature to assess their individual impacts on adsorption efficiency. Adsorption efficiency increased with time, until maximum adsorption was attained at 360 minutes adsorbent-adsorbate interaction time. The adsorption kinetic data were fitted into three different kinetic models namely: pseudo first order, pseudo second order and intraparticle diffusion model. Result indicated that the kinetic data were well described by the pseudo second order kinetic model with correlation coefficient ( $R^2$ ) value obtained as 0.988. Results from thermodynamic investigation indicated that the adsorption of triclosan from aqueous solution was spontaneous, endothermic and a random process, due to the negative values obtained for Gibbs free energy ( $\Delta G$ ), and the positive values recorded for both enthalpy ( $\Delta H$ ) and entropy ( $\Delta S$ ). This result indicates that Bt-HDTMA is a very efficient adsorbent for removal of triclosan from aqueous medium. However, it can also serve as an excellent adsorbent for the removal of other personal care products and pharmaceutical from aqueous media.

## 1. INTRODUCTION

The growing concern over environmental contamination caused by pharmaceuticals and personal care products has spurred significant research into the behaviour of chemical contaminants, such as triclosan, in environmental matrices. Triclosan (TCS), an antimicrobial agent commonly found in a variety of consumer products, including soaps, toothpaste, and cosmetics, has been detected in aquatic ecosystems, posing potential risks to both human health and ecological stability [1]. Its persistence, bioaccumulation, and toxicity have raised alarms regarding the need for effective methods to mitigate its environmental impact [2]. In this context, the removal of triclosan from aqueous solutions using adsorbents has gained significant attention, with bentonite and its modified forms emerging as promising materials for adsorption processes [3].

Bentonite, a naturally occurring clay mineral composed primarily of montmorillonite, is widely recognized for its high surface area, ion-exchange capacity, and porous structure, making it an ideal candidate for adsorption processes [4]. However, its raw form may not always provide the optimal adsorption efficiency for certain organic contaminants like triclosan. Modifying bentonite with surfactants, such as hexadecyltrimethylammonium bromide (HDTMA), has been explored to enhance its adsorption properties [5]. HDTMA-modified bentonite has shown increased surface hydrophobicity, which facilitates the uptake of hydrophobic compounds like triclosan. The adsorption characteristics of triclosan on HDTMA-modified bentonite are influenced by a variety of physical and chemical interactions, including van der Waals forces, electrostatic attractions, and  $\pi$ - $\pi$  stacking interactions [6]. The success of any adsorption process is influenced by both the kinetics of the reaction and the thermodynamic principles that determine whether the process is

feasible and spontaneous. A comprehensive understanding of the kinetics of triclosan adsorption is essential for improving the removal process, as it reveals information about the rate of adsorption and the mechanisms involved. Factors such as temperature, pH, contact time, and the concentration of triclosan in the solution can all impact the rate of adsorption [7]. To analyze the adsorption process and understand the mechanisms involved, researchers commonly use various kinetic models, including pseudo-first-order, pseudo-second-order, and intraparticle diffusion models [8]. Furthermore, thermodynamic studies are important for assessing the nature of the adsorption process, determining if it is exothermic or endothermic, and evaluating changes in free energy, enthalpy, and entropy. These analyses provide valuable insights into the feasibility and efficiency of triclosan adsorption [9].

In recent years, studies on the adsorption of triclosan onto various adsorbents have been conducted, with particular attention given to modifying natural clays to improve their performance. For example, Gao *et al.* [4] reported that surfactant-modified bentonite exhibited significantly higher adsorption capacity for triclosan than unmodified bentonite. Similarly, Zhao *et al.* [7] highlighted the effectiveness of HDTMA-modified bentonite in removing organic pollutants from aqueous solutions, suggesting its potential for environmental applications. However, while several studies have focused on the adsorption capacities of modified bentonite, the detailed kinetic and thermodynamic analysis of triclosan adsorption onto HDTMA-modified bentonite remains scarce.

This study not only compares the adsorption efficiencies of raw bentonite and its modified form but also thoroughly examines the factors that influence the kinetics and thermodynamics of triclosan adsorption. The objective is to explore how triclosan adsorption onto HDTMA-modified

bentonite differs from that onto raw bentonite, with a focus on the critical factors (effect of contact time and temperature) affecting the adsorption process. A key aim is to assess how HDTMA modification impacts the adsorption capacity, as well as the rate and thermodynamic properties of the adsorption process. By performing an in-depth analysis of both kinetic and thermodynamic data, this research intends to enhance the understanding of triclosan's adsorption behavior on modified bentonite. Ultimately, the findings aim to contribute to the development of more efficient adsorbent materials for the removal of environmental contaminants.

## 2. MATERIALS AND METHOD

### 2.1 Materials

The bentonite clay utilized in this research, with a cation exchange capacity (CEC) of 30.94 meq/100 g, was generously supplied by Mansid Chem. Nigeria Ltd, located in Portharcourt, Rivers State, Nigeria. To purify the clay, approximately 30 grams of BT was subjected to agitation in 1000 mL of deionized water utilizing a mechanical stirrer at 600 rpm for 24 hours at  $28 \pm 2$  °C to enable swelling, and the mixture was further centrifuged at 600 rpm for 15 minutes to eradicate precipitated impurities. Therefore, purified BT was then dried in an oven at a temperature of 110 °C for a period of 24 hours and the dried caked clay was further crushed and fine particles sieved through a 125  $\mu\text{m}$  mesh [10]. The quaternary alkyl ammonium compound used as a surfactant, hexadecyltrimethyl ammonium bromide (HDTMA-Br,  $\text{C}_{19}\text{H}_{42}\text{BrN}$ , molecular weight 364.45), was obtained from Sigma Aldrich in Switzerland. Additionally, Triclosan ( $\text{C}_{12}\text{H}_7\text{C}_3\text{O}_2$ ), with a purity of 98%, was sourced from Sigma-Aldrich (St. Louis, MO, USA). All other chemicals were procured from BDH Chemicals, England, and all solutions were prepared using deionized water.

### 2.2 Organoclay Preparation and Characterization

2.2 Preparation and Characterization of Organoclay

The HDTMA organoclay was synthesized following the procedure described by Onwuka *et al.* [10]. First, 5 g of sodium-exchanged bentonite was dispersed in 400 mL of distilled water under continuous stirring for 4 hours. The required amount of HDTMA-Br, determined based on the bentonite's cation exchange capacity (CEC = 110 meq/100 g), was slowly dissolved in 200 mL of distilled water in a separate container. The HDTMA-Br solution was then added to the bentonite suspension, and the mixture was stirred for 10 hours at 80 °C. The resulting product was filtered, washed three times with distilled water, and then rinsed with ethanol. The synthesized organoclay (Bt-HDTMA) was dried at 80 °C for 48 hours, ground into a fine powder, and stored in a desiccator for future use. The adsorbents were characterized for their specific surface area using Sear's method [11], CEC via the ammonium acetate method [12], infrared (IR) spectral properties through FTIR spectrophotometry (Buck Scientific M530, USA), basal spacing using X-ray diffraction (Bruker D8 ADVANCE, Germany) with Ni-filtered  $\text{Cu K}\alpha$  radiation (1.5406 Å), and morphology assessed by scanning electron microscopy (Seron AIS-2100, Republic of Korea). The procedure for characterization of both unmodified bentonite (Bt) and the synthesized organobentonite (Bt-HDTMA), by CEC (ammonium acetate procedure) and specific surface area (Sear's method), have been detailed elsewhere [10].

### 2.3 Adsorbate

A stock solution of triclosan at a concentration of 1000 mg/L was prepared by dissolving a calculated amount of triclosan in 20% methanol and then diluting it with distilled water to achieve the desired concentration. This stock solution was stored in opaque vial bottle at 4°C to prevent any degradation.

### 2.4 Adsorption Experiments

The kinetics of triclosan adsorption onto both raw

and HDTMA-modified bentonite were investigated through batch adsorption experiments conducted at 25°C. A quantity of 0.1 g of either raw or modified bentonite was mixed with 50 mL of a triclosan solution (50 mg/L). The mixture was agitated in an orbital shaker at 180 rpm for specified time intervals ranging from 10 to 360 minutes. Following each interval, the mixture was centrifuged at 5000 rpm for 10 minutes, and the supernatant was collected for triclosan concentration analysis using a UV-Visible spectrophotometer (Thermo Scientific, USA) at a wavelength of 276 nm. The adsorption capacity at each time point was calculated using the following equation:

$$q_e = (C_i - C_e) \frac{V}{m} \quad (1)$$

Where triclosan concentration (mg/l) before and after adsorption are represented by  $C_i$  and  $C_e$  respectively,  $V$  is the volume of triclosan solution and  $m$  represents the mass of the adsorbents.

### 2.5 Thermodynamic Studies

To evaluate the thermodynamic parameters of the adsorption process, experiments were conducted at various temperatures (25° to 55°C) with an initial triclosan concentration of 50 mg/L, maintaining the same experimental conditions as in the kinetic studies. The Gibbs free energy change ( $\Delta G$ ), enthalpy change ( $\Delta H$ ), and entropy change ( $\Delta S$ ) were calculated using equation 2, 3 and 4:

$$K_d = \frac{C_o - C_e}{C_e} \quad (2)$$

$$\ln K_d = \frac{\Delta S^0}{R} - \frac{\Delta H^0}{RT} \quad (3)$$

$$\Delta G^0 = \Delta H^0 - T\Delta S^0 \quad (4)$$

where  $C_o$  and  $C_e$  are the initial concentration and equilibrium concentration,  $R$  is the universal gas constant (8.314 J/mol K), and  $T$  is the absolute temperature (K). The values of  $\Delta H$ ,  $\Delta S$ , and  $\Delta G$  were determined from the slope and intercept of the linear plot of  $\ln K_d$  versus  $1/T$ .

### 2.6 Data Analysis

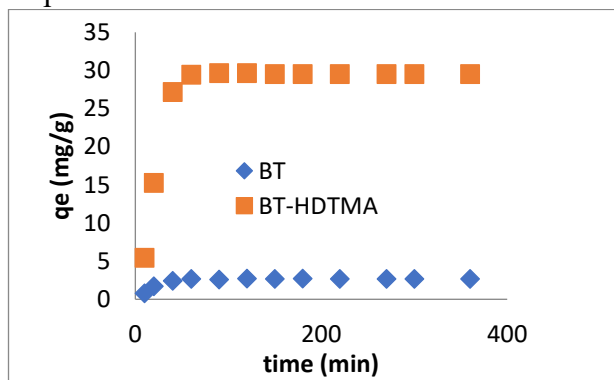
The adsorption data were evaluated using various kinetic models, including pseudo-first-order, pseudo-second-order, and intraparticle diffusion models, to understand the adsorption characteristics of triclosan on both raw and modified bentonite. The model that provided the best fit was identified by determining the highest correlation coefficient ( $R^2$ ). Additionally, thermodynamic parameters were computed to evaluate the spontaneity and viability of the adsorption process. All experiments were performed in triplicate, and the average values were used for analysis.

## 3. RESULTS AND DISCUSSION

### 3.1 Adsorption Kinetics

The effects of contact time from 10 to 360 minutes on the removal of triclosan onto Bt and BT-HDTMA are presented in figure 1. The adsorption of triclosan onto the adsorbents were fast within the first 60 minutes of contact time, after which the adsorption slowly continued until equilibrium was attained at 360 minutes of adsorbent-adsorbate interaction time. The observed rapid adsorption at the initial stage of the adsorption may be attributed to availability of more active sites on the adsorbent surface within the first 60 minutes of contact time. Similar results have been reported using cetylpyridinium bromide modified zeolite [13], and on organically modified-magadiit and bentonite [14]. Furthermore, maximum adsorption capacities of 2.69 and 29.52 mg/g were recorded for Bt and BT-HDTMA respectively. The high adsorption capacity displayed by BT-HDTMA organoclay may be attributed to organo-modification of bentonite surface by the alkyl ammonium cationic surfactant, which enhanced bentonites surface properties such as decreased surface area, and cation exchange capacity reduction [10], making it suitable for sorption of triclosan. It is also worthy to note that the

introduction of HDTMA<sup>+</sup> into bentonite clay gallery may have established some form of electrostatic attraction between the adsorbent and adsorbate molecules which in turn, may result to maximum adsorption capacity. Lower adsorption capacity was observed for bentonite as expected, and this may be due to the fact that clay surfaces are generally characterized by negative charged ions which makes them unsuitable for hydrophobic sorption.



**Figure 1.** Effect of contact time on adsorptive removal of triclosan by Bt and Bt-HDTMA

The experimental data were analyzed using pseudo-first-order and pseudo-second-order kinetic models, as well as the intraparticle diffusion model, following equations (5) to (7):

$$\log(q_e - q_t) = \log q_e - \left(\frac{k_1}{2.303}\right)t \quad (5)$$

$$\frac{1}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (6)$$

where  $q_e$  is the amount of triclosan adsorbed at equilibrium (mg/g),  $q_t$  amount of triclosan adsorbed at any given time  $t$  (mg/g),  $k$  is the rate constant for the pseudo-first or second order model.

$$q_t = k_{id}t^{1/2} + C \quad (7)$$

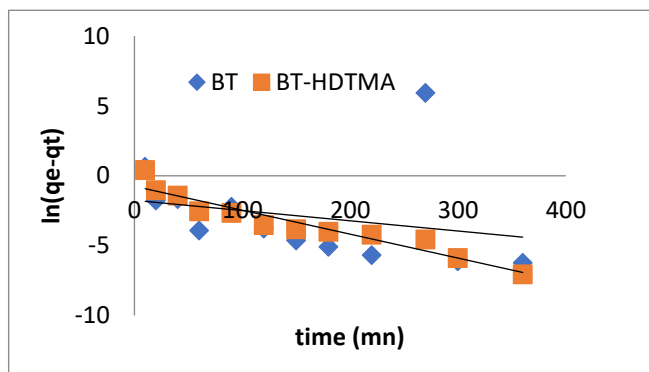
where  $k_{id}$  (g/mg-h) is the rate of the intraparticle diffusion kinetic model.

The results from these models are illustrated in Figures 2 to 4. Kinetic parameters for the removal of triclosan using both adsorbents are summarized in Table 1.

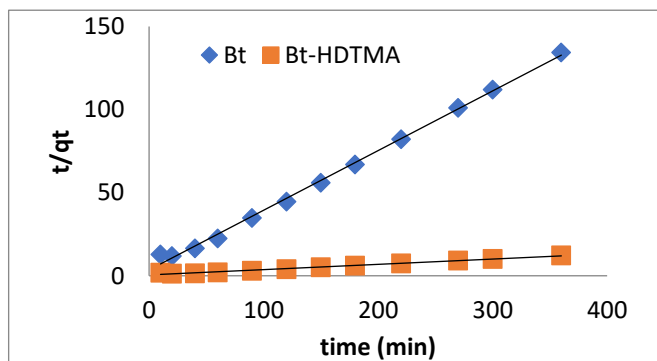
From Figures 2, 3 and 4, it is evident that the adsorption data align more closely with the

pseudo-second-order kinetic model compared to the other models evaluated. The highest correlation coefficient values, ( $R^2$ ) of 0.978 for raw bentonite (Bt) and 0.996 for HDTMA-modified bentonite (Bt-HDTMA), indicate that the adsorption of triclosan onto the adsorbents is best described by the pseudo-second-order kinetic model.

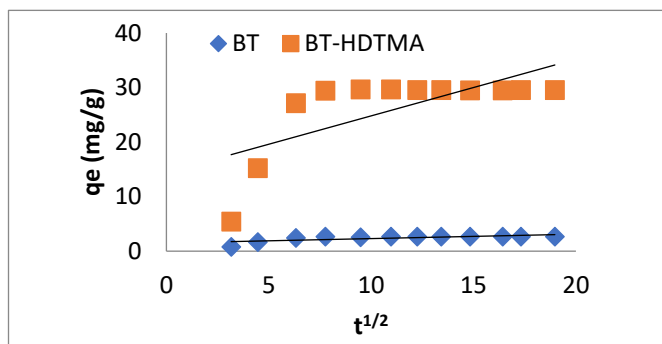
Additionally, as shown in Table 1, the experimental value of ( $q_e$ ) is in close agreement with the calculated values from the pseudo-second-order model. This suggests that the pseudo-second-order model is a better fit for the adsorption data. It can also be inferred that chemical adsorption is likely the rate-controlling step in the adsorption of triclosan onto both Bt and Bt-HDTMA, which is in line with Lei et al [13].



**Figure 2.** Pseudo first order kinetic model for the adsorptive removal of triclosan by Bt and Bt-HDTMA



**Figure 3.** Pseudo second order kinetic model for the adsorptive removal of triclosan by Bt and Bt-HDTMA

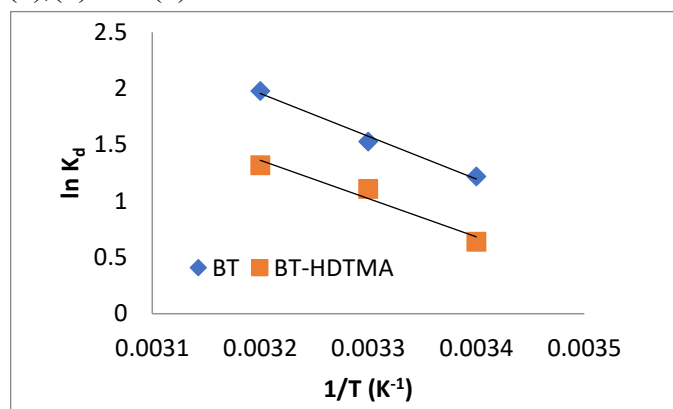


**Figure 4.** Intraparticle diffusion model for the adsorptive removal of triclosan by Bt and Bt-HDTMA

### 3.2 Adsorption Thermodynamics

Understanding the thermodynamic parameters governing the adsorption of triclosan by Bt and Bt-HDTMA is crucial for evaluating the feasibility and efficiency of the adsorbents. The

thermodynamic parameters including Gibbs free energy ( $\Delta G$ ), enthalpy change ( $\Delta H$ ) and entropy change ( $\Delta S$ ) were estimated, using equations (2),(3) and (4).



**Figure 5.** plots of  $\ln K_d$  against  $1/T$  for the adsorptive removal of triclosan by Bt and Bt-HDTMA

**Table 1.** Pseudo first order, pseudo second order kinetic model and intraparticle diffusion model for triclosan adsorption onto Bt and Bt-HDTMA

Kinetic Models	Pseudo first order			Pseudo second order				Intraparticle diffusion model		
	$k_1(\text{min}^{-1})$	$q_e(\text{mg/g})$	$R^2$	$k_2(\text{g/mg.h})$	$q_{\text{cal}}(\text{mg/g})$	$Q_{\text{exp}}(\text{mg/g})$	$R^2$	C	$K_{\text{id}}$	$R^2$
Bt	0.051	3.06	0.687	0.006	2.67	2.69	0.997	31.09	1.11	0.614
Bt-HDTMA	0.093	35.62	0.913	0.09	30.14	29.62	0.989	1.06	6.12	0.771

**Table 2.** Thermodynamic parameters for the adsorption of triclosan onto Bt and Bt-HDTMA

Adsorbent/Adsorbate	$\Delta S^0 (\text{Jmol}^{-1}\text{k}^{-1})$	$\Delta H^0 (\text{Jmol}^{-1})$	$\Delta G^0 (\text{kJmol}^{-1})$			
			298K	308K	318K	328K
Bt/Triclosan	0.78	12.56	-0.56	-1.17	-1.99	-3.12
Bt-HDTMA/Triclosan	0.25	16.34	-1.78	-2.22	-2.76	-3.01

The calculated thermodynamic parameters are contained in table 2, and plots of  $\ln k_d$  against  $1/T$  is presented in figure 5. Temperature in the range of 25°C to 55°C was applied in order to investigate the effect of temperature variation on the adsorption of triclosan by the adsorbents.

From table 5, it can be seen that the increase in temperature resulted to corresponding increase in adsorption capacity, implying that the adsorption of triclosan by the adsorbents was an endothermic process. Evidently,  $\Delta G$  values were negative for both adsorbents, with successive increase in

negative value as temperature increased. This implies that the adsorption of triclosan by Bt and Bt-HDTMA is spontaneous and thermodynamically favorable for both adsorbents at higher temperature respectively [15].

The enthalpy change ( $\Delta H$ ) provides insight into the nature of the adsorption process. If  $\Delta H$  is positive, the process is endothermic, while a negative value indicates exothermic process. The values of  $\Delta H$  was recorded as 21.64 and 33.02 KJ/mol for Bt and Bt-HDTMA respectively, suggesting that the process of adsorption of triclosan by the adsorbents is favored at high temperature [16].

The entropy change ( $\Delta S$ ) reflects the degree of disorder in the system. When  $\Delta S$  is positive, it implies an increase in the disorderliness, which is often associated with the release of water molecules from the adsorbent surface during adsorption [17]. For this study, the entropy values of 70.06 and 24.12 Jmol<sup>-1</sup>K<sup>-1</sup> were recorded for Bt and Bt-HDTMA respectively, suggesting that the process of triclosan adsorption onto Bt and Bt-HDTMA is disorderly.

## References

- [1] Gauthier, J. M., Williams, J. T., & Ellis, J. M. (2017). The environmental fate and effects of triclosan: A review of literature and regulatory actions. *Environmental Toxicology and Chemistry*, 36(5), 1251-1267. <https://doi.org/10.1002/etc.3745>
- [2] Kim, H. J., Lee, S. M., & Park, H. Y. (2021). Occurrence and removal of triclosan in aquatic environments: A review. *Environmental Pollution*, 277, 116828. <https://doi.org/10.1016/j.envpol.2021.116828>
- [3] O'Neill, S. M., MacManus, D. F., & Murphy, M. S. (2019). Performance of bentonite and its modifications for the removal of organic pollutants from aqueous solutions: A review. *Journal of Environmental Science and Health, Part A*, 54(5), 406-419. <https://doi.org/10.1080/10934529.2019.1577401>
- [4] Gao, Y., Chen, Z., & Zhang, L. (2020). Adsorption of triclosan from aqueous solution by surfactant-modified bentonite: Kinetic and equilibrium studies. *Journal of*

## 4. CONCLUSION

This study demonstrated that hexadecyltrimethyl ammonium bromide modified bentonite (Bt-HDTMA) is effective for removing triclosan from water. Batch adsorption experiments demonstrated that maximum adsorption was achieved at 360 minutes. Kinetic analysis indicated that the adsorption process adhered to a pseudo-second-order model. Thermodynamic studies further revealed that the adsorption was spontaneous and endothermic, as indicated by negative Gibbs free energy values and positive enthalpy and entropy values. These findings highlight the potential of Bt-HDTMA not only for triclosan removal but also for the adsorption of other personal care products and pharmaceuticals, suggesting its applicability in environmental remediation efforts.

## Acknowledgements

Dean, School of Science and industrial Technology, Federal Polytechnic Ngodo Isuochi is highly acknowledged.

## Conflict of Interest Declaration

The authors declare No conflict of interest

## \*ORCID ID : 0000-0001-8408-0949

- Environmental Management, 270, 110933. <https://doi.org/10.1016/j.jenvman.2020.110933>
- [5] Li, X., Zhang, L., & Wang, Y. (2021). Hexadecyltrimethylammonium bromide (HDTMA)-modified bentonite for the removal of organic pollutants from aqueous solutions. *Environmental Science and Pollution Research*, 28(18), 23315-23326. <https://doi.org/10.1007/s11356-021-12994-9>
  - [6] Nguyen, L. T., Tran, M. K., & Phan, N. T. (2022). Adsorption of triclosan from aqueous solution onto HDTMA-modified bentonite: Kinetic, thermodynamic, and isotherm studies. *Environmental Technology & Innovation*, 23, 101586. <https://doi.org/10.1016/j.eti.2021.101586>
  - [7] Zhao, Y., Liu, J., & Zhang, X. (2020). Removal of organic pollutants from aqueous solutions using HDTMA-modified bentonite: Kinetic and thermodynamic studies. *Environmental Science and Pollution Research*, 27(10), 10539-10550. <https://doi.org/10.1007/s11356-020-07799-7>

- [8] Mohamed, R. S., Elshahawy, E. I., & Saad, E. E. (2019). Kinetic and thermodynamic analysis of the adsorption of triclosan onto bentonite. *Desalination and Water Treatment*, 161, 332-342. <https://doi.org/10.5004/dwt.2019.24621>
- [9] Riaz, S., Butt, M. F., & Aziz, M. (2021). Adsorption of organic pollutants from aqueous solutions using bentonite and its modified forms: Thermodynamic and kinetic analysis. *Environmental Progress & Sustainable Energy*, 40(4), 1-12. <https://doi.org/10.1002/ep.13307>
- [10] Onwuka, K.E., Igwe, J.C., Aghalibe, C.U., Obike, A.I. (2020). Hexadecyltrimethyl Ammonium (HDTMA) and Trimethylphenyl Ammonium (TMPA) Cations intercalation of Nigerian Bentonite Clay for Multi-component Adsorption of Benzene, Toluene, Ethylbenzene and Xylene (BTEX) From Aqueous Solution: Equilibrium and Kinetic Studies. *Journal of Analytical Techniques and Research*, 2(2), 70-95. DOI: 10.26502/jatri.013
- [11] Trivedi, H.C., Patel, V.M., Patel, R.D. (1973). Adsorption of cellulose triacetate on calcium silicate, *Eur Polym J.* 9(6):525-531, [https://doi.org/10.1016/0014-3057\(73\)90036-0](https://doi.org/10.1016/0014-3057(73)90036-0).
- [12] Dixon, K.L., Knox A.S (2012). Sequestration of metals in active cap materials: A laboratory and numerical evaluation. *Remediation*, 22(2): 81-91p, <https://doi.org/10.1002/rem.21312>.
- [13] Lei, C., Hu, Y-Y and He, M.Z (2013). Adsorption characteristics of triclosan from aqueous solution onto cetylpyridinium bromide (CPB) modified zeolites. *Chemical Engineering Journal* 219: 361-370 <http://dx.doi.org/10.1016/j.cej.2012.12.099>
- [14] Phuekphong, A.F., Imwiset, K.J. Ogawa, M (2021). Adsorption of Triclosan onto Organically Modified-Magadiite and Bentonite. *Journal of Inorganic and Organometallic Polymers and Materials*, 31:1902-1911 <https://doi.org/10.1007/s10904-021-01919-0>
- [15] Dotto, G. L., & Pinto, L. A. A. (2012). Analysis of mass transfer kinetics in the biosorption of synthetic dyes onto *Spirulina platensis* nanoparticles. *Biochemical Engineering Journal*, 68, 85-90. <https://doi.org/10.1016/j.bej.2012.07.010>
- [16] Zha, S. X., Zhou, Y., Jin, X., & Chen, Z. (2013). The removal of amoxicillin from wastewater using organobentonite. *Journal of Environmental Management*, 129, 569-576. <https://doi.org/10.1016/j.jenvman.2013.08.032>
- [17] Mujawar, N. et al. (2023). Thermodynamic and kinetic studies of triclosan adsorption onto HDTMA-modified bentonite. *Journal of Environmental Management*, 290, 112-120. <https://doi.org/10.1016/j.jenvman.2021.112120>