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Studies on the Use of Snail Shells in the Treatment of Wastewater Effluent

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ABSTRACT

The efficiency of snail shells as adsorbent for treating wastewater from PEMO Food Industry in Edo State was investigated. Treatment was achieved by adsorption of contaminants in wastewater onto snail shell powder. Physicochemical analysis of the treated wastewater was conducted at intervals of 10 minutes for a total treatment time of 120 minutes. Water quality parameters such as pH, Conductivity, BOD, COD, DO, TSS, TDS, TS, Alkalinity, Turbidity, Temperature, Nitrate, Sulphate, Phosphate, Lead, and Cadmium were measured to determine the efficiency of snail shell adsorbent. The statistically observed significant difference at 95% confidence limit ($P \leq 0.05$) for the treatment data indicates the effectiveness of the adsorbent and supports the high efficacy of snail shell in the treatment. Kinetics analysis was carried out by evaluating the time-dependence of the different quality parameters after treatment using Pseudo-First order, Pseudo-Second order, and Intra-particle diffusion models respectively. The results show that the treatment fits Pseudo-Second order kinetics when compared to Pseudo-First order and Intra-particle diffusion model since R^2 values of the parameters showed excellent linearity towards unity ($R^2 \geq 0.99$); except for TSS and Pb which showed deviation from linearity when compared to the other models. Treating wastewater for TSS and Pb followed Intra-particle diffusion kinetics ($R^2 \geq 0.9$). The results of this study demonstrate the efficacy of snail shells as a cost-effective adsorbent and green remediation material in treating wastewater from the food industry, with the observed kinetics providing insightful information and knowledge in understanding the adsorption mechanism of wastewater treatment using snail shells as bio-adsorbent.

Keywords: Adsorption, Food Industry, Kinetics, Wastewater, Snail Shells, Treatment Efficiency

1.0 INTRODUCTION

Due to rapid industrialization arising from modern and sophisticated technologies, different chemical substances have been introduced into our environment, some of which are toxic or carcinogenic, and these have found their way into the water bodies. Wastewater from industrial activities varies momentously in flow, pollution strength and composition [1]. The food industry is one of the most challenging industries, with the wastewater generated from it posing a possible threat to the natural water bodies and the environment at large. Wastewater from food industries contains solid wastes with varying amounts of organic materials such as the grains and shafts from the organic feedstock. The total amount of solid waste generated depends on the movement of materials during the processing period and the amount of the inorganic and organic substances that contribute to the total solid component of the wastewater. Wastes from the food industry contain high concentrations of ions that are dissociated from compositional feedstock materials such as protein, carbohydrates, starch, cellulose, phytate found in most grains and many other substances. Food processing industries utilize large volumes of water, and the wastewater generated contains a heavy load of organic compounds which are lethal to living organisms in the ecosystem [2]. Wastewater from food processing industries is quite different from other industrial wastewater as they are highly degradable. However, they have high concentrations of biochemical oxygen demand (BOD) and suspended solids [1]. There are existing approaches for the management of wastewater from the food industry. Bio-sorption, a process whereby certain types of sedentary dead biomass (such as snail shell, peat, rice husk, fruit peels, etc.) may bind and concentrate organic matters and different pollutants from aqueous solution is considered an alternative technology for the removal of organic matters and other pollutants from wastewater and industrial effluents [3]. Bio-sorption technology is advantageous due to the cost-effectiveness of bio-sorbents (biomass) since they are derived from cheap sources. A range of adsorbents had been examined, such as clay, charcoal, cassava waste, etc. In general, there are various methods for the treatment of wastewater, some of such include, chemical precipitation, ion exchange, adsorption, membrane processes, supercritical fluid extraction, bioremediation, and oxidation with oxidizing agents [4]. However, most of these technologies are either very expensive or ineffective in the treatment of wastewater. Efficient and environmentally friendly methods are thus needed to be developed. It is observed that adsorption among other methods is a cost-effective technique that is simple to operate.

In contrast to the study of adsorption using activated carbon, and different agricultural and animal byproducts, information about the use of snail shells as an adsorbent is limited in literature. The only related information available in literature is on the use of chitosan in the treatment of wastewater [5]. Snails belong to the phylum Mollusk and class of Gastropods. The gastropods are the largest class of the phylum Mollusk [6], a group of animals commonly known as snails and slugs. The shell which is naturally very hard protects the snail from physical damage, predators, and dehydration. Recent development involves its application in the treatment of water and wastewater as a result of its chemical composition and large surface area; this composition includes proteins, carbohydrates, fats, and minerals such as iron, zinc, copper, etc. [7].

This study aimed to determine the efficacy of powdered snail shells as bio-adsorbents in the treatment of wastewater from PEMO Food Industry situated in Edo State, as well as establish the optimum wastewater treatment time from kinetics studies. An important environmental waste-to-wealth approach requiring the conversion of snail shells to useful remediating agents which will serve as alternative adsorbent materials that are locally sourced for the treatment of food industry wastewater was of primary focus in this study.

2.0 MATERIALS AND METHODS

2.1 Wastewater

Wastewater samples were collected from PEMO Food Industry Limited, located at Aviele in Etsako West Local Government Area of Edo State, South-South Nigeria. The industry is situated at Km 124 Benin-Auchi Expressway Aviele, Edo State. Geographically, the industry lies between longitude 5° East and 6.45° East and latitude 6.1° North and 7.30° North.

PEMO Foods Industry is a growing agro-allied food manufacturing company that is over ten years old in Aviele, Edo State, Nigeria. They are involved in the production of dairy milk, plantain flour, rice flour, grapet rice, cornflakes, and cereals. They generate large volumes of wastewater from their production activities which is discharged into a septic tank without treatment.

2.2 Snail Shells

The giant African snail shells were collected from hotel kitchens and restaurants within Ekpoma, Esan West Local Government area of Edo State Nigeria. The shells were washed with hot water to remove sand and dirt, after which it was sun-dried. The snail shells were then homogenized by grinding to a fine powder and sieved using a 0.5 μm pore size sieve to obtain a uniform fine powder.

2.3 Analysis of the wastewater

The pH and temperature of the wastewater were determined *in situ* on site. Thereafter, the wastewater was preserved in a refrigerator at a temperature of 4 °C to inhibit bacteria activities and microbial biodegradation before analysis. The determination of pH, temperature, turbidity, alkalinity, total suspended solids, total solids, total dissolved solids, electrical conductivity, biochemical oxygen demand, chemical oxygen demand, dissolved oxygen, phosphate, sulphate, nitrate, lead, and cadmium was carried out following standard methods [8].

2.4 Kinetics studies

50 g of snail shell was weighed into a 500 ml capacity beaker, and 100 ml of the wastewater was added and stirred using an orbital shaker at 500 rev/min. Samples were taken, filtered, and analyzed for water quality parameters at time intervals (1, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, and 120 minutes.) Kinetics analysis was carried out by testing the treatment efficiency of the snail shell adsorbent on different kinetics models to establish their characteristics using the regression coefficients obtained. The efficiency of the treatment process was also validated statistically using Analysis of Variance (ANOVA) as a statistical tool for calculating the data obtained from the water quality treatment efficiency indexes. Three kinetic models [9-11], Lagergran Pseudo-First order, Pseudo-Second order, and Intra-particle diffusion were considered to interpret the time-dependent experimental data.

(a) The Lagergren Pseudo-First order equation is given as

$$\log(q_e - q_t) = \log q_e - \frac{k_{p1}}{2.303}t \quad (1)$$

Where q_e and q_t (mg/g) are the adsorption capacity at equilibrium and time t (min), respectively.

kp^1 (min^{-1}) is the pseudo-first-order rate constant for the kinetic model.

(b) The Pseudo-Second order kinetic model equation is given as

$$\frac{t}{q_t} = \frac{1}{v_o} + \frac{1}{q_e}t \;\; \& \;\; v_o = kp^2 q_e^2 \quad (2)$$

where v_o (mg/g.min) is the initial adsorption rate and the constant can be determined experimentally by plotting t/qt against t.

(c) The Intra-particle diffusion model equations is given as

$$q_t = k_{int} t^{½} \quad (3)$$

Where k_{int} is the Intra-particle diffusion rate constant. According to the above equation, a plot of qt vs. $t^{½}$ should be a straight line with a slope of k_{int} where the Intra-particle diffusion is the rate-limiting step.

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3.0 RESULTS AND DISCUSSION

The results of the physicochemical analysis of wastewater from the food industry are shown in Table 1 below.

Table1. Results of physicochemical parameters of untreated wastewater from the food industry

Parameter	Value (Mean ± SD)	WHO/FME Standard
pH	8.80 ± 0.30	6.50 - 8.50 (WHO)
Temperature (°C)	27.60 ± 0.50	-
Alkalinity (mg/L)	678.00 ± 2.00	-
Turbidity (mg/L)	10.18 ± 0.30	5.00 (WHO)
TDS (mg/L)	77.00 ± 1.00	500 (FME)
TSS (mg/L)	115.70 ± 1.50	1000 (FME)
TS (mg/L)	194.00 ± 0.10	1000 (FME)
Conductivity (μS/cm)	152.70 ± 0.60	250 (FME)
BOD (mg/L)	959.30 ± 1.20	7.50 (FME)
COD (mg/L)	1806.18 ± 0.50	10 (FME)
DO (mg/L)	3.10 ± 0.10	4.00 (FME)
Phosphate (mg/L)	1.53 ± 0.10	5.00 (FME)
Sulphate (mg/L)	3.326 ± 0.10	500 (WHO)
NO_3-N (mg/L)	1.09 ± 0.10	50 (WHO)
Pb (mg/L)	1.01 ± 0.30	0.01 (WHO)
Cd (mg/L)	BDL	0.003(WHO)

BDL: Below Detection Limit; **WHO**: World Health Organization; **FME**: Federal Ministry of Environment

The pH value of 8.80 of the wastewater (Table 1) is an indication that the wastewater generated from the food industry is slightly alkaline. This results from the high organic load and high salt concentration which are instigated by the regeneration of the water-softening column and the alkaline cleaning solution from the bottling processing line [12].

In most food processing industries, the waste can be co-digested with other waste substances containing nitrogen compounds which will increase the pH of the wastewater, hence the slight alkalinity of the wastewater. The pH value is seen to be above the permissible limit [13] which makes it unsafe to be discharged into the environment, there is therefore need for treatment before discharge.

The temperature value of 27.6 °C for the untreated wastewater as seen in Table 1 was within the acceptable limit for the safe discharge of wastewater. At this temperature, the metabolic activities of organisms in the wastewater will not be high, and there will be a reduction in the utilization of dissolved oxygen.

The value for alkalinity is 678.00 mg/L. The untreated wastewater from the food industry was slightly turbid with a value of 10.18 NTU. This is an indication that the wastewater contains large amounts of dissolved and suspended solids [14]. The value for electrical conductivity is 152.70 μS/cm, while the value of 115.70 mg/L is seen for suspended solids. The BOD value of 959.30 mg/L for the untreated wastewater seems to be quite high compared to the recommended WHO standard of 50 mg/L. This shows that the wastewater generated from this food industry contains a high concentration of organic substances that are susceptible to microbial degradation. As can be seen in Table 1, the COD value of 1806.18 mg/L is also very high, indicating significant pollution level in the wastewater. The COD value is seen to be above the recommended standard for safe water [15], hence the need for treatment before discharge into the environment. The dissolved oxygen value of 3.10 mg/L is observed to be lower than the FME recommended levels [15]. This is an indication that the wastewater contains a high concentration of contaminants that utilize the dissolved oxygen in the wastewater. It also indicates pollution of the wastewater since a healthy water body should have at least 5.0 mg/L [14]. Phosphate, sulphate and nitrate values were found as 1.53 mg/L, 3.33 mg/L, and 1.09 mg/L respectively. These values are below WHO recommended levels [13] and as such pose no significant pollution risk. However, a bioaccumulation of these ions in the water body when the wastewater is discharged into it could lead to the proliferation of plankton and other plants, giving rise to eutrophication and algae bloom in water body, with the likelihood of causing pollution of the water body; hence the need for treatment before discharge.

The value of lead is found as 1.01 mg/l in the untreated wastewater. The value is seen to be quite high when compared to safe recommended levels [13], as such constitutes severe pollution risk when discharged into the environment and acute toxicity to aquatic life when bio-accumulated. The presence of lead may be attributed to mechanical activities during process unit operation that occurs in the food processing chain. Cadmium was below detection limits in the wastewater analyzed, an indication that the waste by-products from the food industry are devoid of cadmium presence; hence possess no cadmium threat or toxicity. The results of the physicochemical analysis of the treated wastewater at different time intervals are presented in Table 2 below.

Table 2. The physicochemical analysis Results of the treated wastewater at different time intervals.

PARAMETERS	**TIME (MINUTES)**										
	1	10	20	30	40	50	60	70	80	90	120
pH	7.40 ± 0.01	7.80 ± 0.01	8.10 ± 0.02	8.10 ± 0.01	8.30 ± 0.03	8.20 ± 0.01	8.3.00 ± 0.02	8.3 0± 0.01	8.00 ± 0.04	8.40 ± 0.02	8.70 ± 0.01
Temperature (°C)	27.00 ± 0.04	27.0 ± 0.03	28.00 ± 0.04	28.00 ± 0.02	28.00 ± 0.01	28.00 ± 0.05	28.00 ± 0.03	28.00 ± 0.02	28.00 ± 0.01	28.00 ± 0.04	27.00 ± 0.02
Alkalinity (mg/L)	642.00 ± 2.00	636.00 ± 2.50	620.00 ± 2.10	601.00 ± 1.50	580.00 ± 2.00	566.00 ± 2.00	562.00 ± 2.20	560.00 ± 2.10	561.00 ± 2.10	558.00 ± 1.20	558.00 ± 2.40
Turbidity (NTU)	9.84 ± 1.40	9.84 ± 1.60	8.52 ± 1.80	8.51 ± 2.00	8.52 ± 2.10	8.42 ± 2.10	8.17 ± 1.30	8.14 ± 2.10	8.14 ± 2.20	8.13 ± 1.40	8.12 ± 1.50
TDS (mg/L)	60.00 ± 0.50	56.00 ± 0.40	54.00 ± 0.40	52.00 ± 1.50	50.00 ± 0.60	50.00 ± 1.20	50.00 ± 0.40	48.00 ± 1.50	48.00 ± 2.10	47.00 ± 1.30	46.00 ± 0.60
TSS (mg/L)	9.82 ± 0.40	8.64 ± 0.50	4.82 ± 0.50	3.61 ± 1.50	2.42 ± 0.30	1.24 ± 2.00	1.06 ± 0.40	1.02 ± 0.40	0.08 ± 0.01	0.06 ± 1.20	0.02 ± 0.30
TS (mg/L)	69.82 ± 0.20	64.64 ± 0.10	58.82 ± 0.40	56.02 ± 0.50	52.42 ± 0.30	52.31 ± 2.10	51.06 ± 0.30	48.01 ± 0.20	48.02 ± 1.50	47.86 ± 1.20	46.02 ± 0.10
Conductivity (µS/cm)	121.00 ± 2.30	115.00 ± 3.00	119.00 ± 2.40	114.00 ± 1.50	113.00 ± 2.40	112.00 ± 0.10	111.00 ± 2.50	111.00 ± 0.10	112.00 ± 0.40	112.00 ± 2.50	112.00 ± 2.60
BOD (mg/L)	45.31 ± 0.40	40.16 ± 0.50	32.18 ± 0.50	32.00 ± 1.20	31.85 ± 0.30	31.81 ± 1.00	31.85 ± 0.60	31.62 ± 1.50	31.09 ± 1.50	30.56 ± 2.10	30.42 ± 0.40
COD (mg/L)	642.00 ± 0.60	634.00 ± 0.50	630.00 ± 0.70	630.00 ± 2.00	626.00 ± 0.60	622.00 ± 0.50	610.00 ± 0.60	608.00 ± 1.20	608.00 ± 1.40	606.00 ± 2.00	605.00 ± 0.50
DO (mg/L)	4.52 ± 0.40	4.56 ± 0.60	4.80 ± 0.50	4.81 ± 2.10	5.02 ± 0.60	5.06 ± 1.50	5.06 ± 0.50	5.07 ± 1.30	5.08 ± 2.00	5.08 ± 0.50	5.08 ± 0.60
Phosphate (mg/L)	1.17 ± 1.40	1.17 ± 2.10	1.16 ± 1.50	1.13 ± 2.00	1.04 ± 1.40	1.04 ± 1.60	1.02 ± 2.00	1.03 ± 1.50	1.02 ± 1.50	1.01 ± 2.00	1.00 ± 2.10
Sulphate (mg/L)	2.50 ± 2.10	2.41 ± 1.50	2.25 ± 2.00	2.20 ± 1.50	2.11 ± 2.10	2.01 ± 1.50	1.80 ± 2.20	1.80 ± 1.50	1.75 ± 2.00	1.64 ± 2.00	1.62 ± 2.20
NO_3-N (mg/L)	1.06 ± 1.20	1.05 ± 1.30	1.02 ± 1.30	1.20 ± 1.30	1.01 ± 1.20	1.00 ± 1.60	0.64 ± 1.20	0.52 ± 2.00	0.51 ± 2.10	0.21 ± 2.00	0.10 ± 1.20
Pb (mg/L)	0.15 ± 2.30	0.14 ± 2.20	0.10 ± 2.30	0.10 ± 2.10	0.10 ± 2.40	0.09 ± 2.00	0.0 8± 2.40	0.06 ± 1.50	0.06 ± 1.50	0.04 ± 2.50	0.04 ± 2.40
Cd (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

BDL: Below Detection Limit

From Table 2 above, the pH value decreased from 8.80 in the untreated wastewater to 7.40 and 7.80 at one-minute and 10-minute contact with the adsorbent respectively. The pH value increased slightly with increased treatment time. The values were however marginally lower than the pH value of the untreated water (8.80) which shows a slight reduction in alkalinity after treatment. The pH values were within the acceptable limit of between 5.0-9.0 for wastewater [16]. This result agrees with the report of Nyilibambazi et al. [17] for the treatment of wastewater from breweries. The temperature values of between 27 °C and 28 °C recorded at different times of treatment are within the 27 – 29 °C range for the safe discharge of wastewater into the environment and receiving water bodies [16]. The turbidity value reduced from 10.18 to 9.84 mg/L at one minute of treatment and further reduced steadily to 8.12 mg/L after 120 minutes of treatment. This shows an improvement in turbidity level after treatment. TSS value reduced significantly from 117.7 to 9.82 mg/L at one-minute of treatment and further reduced progressively up to 0.02 mg/L after 120 minutes of treatment. The reduction in turbidity after treatment is likely due to the removal of colloidal substances from the wastewater, while the almost complete removal of suspended solids indicates the strong potential of snail shell as a good adsorbent in the treatment of wastewater. Dissolved oxygen increased from 3.10 mg/L in the untreated wastewater to 4.52 mg/L at one minute of treatment, and increased progressively thereafter to 5.08 mg/L after 120 minutes of treatment. This significant increase in the value of dissolved oxygen after treatment is a reflection of the remediation potential of the powdered snail shell as a viable adsorbent for the treatment of wastewater. Alkalinity decreased slightly from 678.00 mg/L for the untreated wastewater to 642.00 mg/L at one minute treatment time, with a further progressive decrease to 558.00 mg/L as treatment time increased up to 120 minutes. A significant reduction in COD values is seen from an initial value of 1806.18 mg/L in the untreated wastewater to 642.00 mg/L at one minute treatment, and steadily decreases to 605.00 mg/L as treatment time increased up to 120 minutes. COD value is reduced progressively as the treatment time increases. This decrease in chemical oxygen demand indicates the removal of most dissolved and suspended substances that are susceptible to oxidation from the wastewater by the snail shell. However, the value is slightly higher than the FEPA permissible value of 80 mg/L [16] in the discharge of wastewater, hence further treatment is required to reduce COD level.

The total dissolved solid was reduced to 60.00 mg/L from 77.00 mg/L in the untreated wastewater after the first minute of treatment and reduced progressively to 46.00 mg/L as treatment time increased up to 120 minutes. This reduction may be due to the adsorption of most of the solid wastes in suspended or dissolved form by the powdered snail shell.

BOD value decreased significantly from 959.30 mg/L in the untreated wastewater to 45.31 mg/L after one minute of treatment time. BOD value decreased steadily to 30.42 mg/L as treatment time increased up to 120 minutes, amounting to about 95% BOD reduction. The significant BOD reduction after treatment shows the efficacy of the snail shell in wastewater treatment with regard to BOD. The value of 30.42 mg/L obtained after 120 minutes of treatment time is comparable to the acceptable limit of 30 mg/L recommended by FEPA [16] for wastewater discharge.

Phosphate had a value of 1.53 mg/L in the wastewater, but reduced to 1.17 mg/L at one minute of treatment time, and reduced further to 1.00 mg/L after 120 minutes of treatment time. Sulphate also reduced from 3.30 mg/L in wastewater to 2.50 mg/L at one minute of treatment time, and reduced further to 1.62 mg/L after 120 minutes of treatment time. A reduction in nitrate level from 1.09 mg/L in the wastewater to 1.06 mg/L at one minute of treatment time was observed, with a further reduction to 0.10 mg/L after 120 minutes of treatment time. This reduction in phosphate, sulphate and nitrate with increasing treatment time shows the efficiency of the snail shell as an adsorbent in the treatment of wastewater. Kolhe *et al*. [18] observed a similar reduction in these ions in the treatment of sugar mill effluent with activated carbon from banana husk.

Lead concentration was reduced from 1.01 mg/L in the untreated wastewater to 0.15 mg/L at one minute of treatment time and progressively reduced to 0.04 mg/L after 120 minutes treatment time. The significant reduction in the concentration of lead after 120 minutes shows the efficacy of powdered snail shells as an adsorbent in reducing the metal level in wastewater. However, cadmium was below the detectable limit in the treated wastewater. The large surface area and the presence of calcium and iron (111) in the powdered snail shell [7] could be responsible for the efficiency of the adsorbent in the treatment of wastewater.

A summarized statistical analysis of all water quality treatment efficiency indicators using ANOVA gave a significant difference at a 95% confidence limit ($P \leq 0.05$) between water quality parameters in the food industry wastewater and the treated water using powdered snail shell. This statistical evidence further justifies the efficacy and effectiveness of the treatment technique using snail shells as a green bio-adsorbent for food industry wastewater remediation.

3.1 Kinetics Studies of the Treatment of Wastewater from the Food Industry

The treatment of wastewater from the food industry was subjected to kinetics evaluation using the Lagagren (Pseudo-First order) rate equation, Pseudo-Second order rate equation, and Intra-particle diffusion model, to ascertain which of the models fits the kinetics of treatment.

The results obtained from the kinetics studies are presented in Table 3.

Table 3: Data of Kinetics studies of Wastewater Treatment from the food industry

Parameters	Pseudo-First order		Pseudo-Second order		Intra-particle Diffusion	
	K_1	R^2	K_2	R^2	K_{int}	R^2
pH	0.08	0.962	7.399	0.999	0.127	0.949
Temperature (°C)	-	-	-0.023	0.999	0.028	0.034
Alkalinity (mg/L)	0.004	0.719	-0.002	0.999	1.308	0.022
Turbidity	0.006	0.498	-0.148	0.999	-0.197	0.733
Conductivity (μS/cm)	-0.002	0.774	0.012	0.999	1.363	0.525
TS (mg/L)	0.001	0.785	-0.076	0.997	0.957	0.956
TSS (mg/L)	0.0003	0.734	-1034	0.770	-1.091	0.905
TDS (mg/L)	0.002	0.762	-0.052	0.998	-1.401	0.966
BOD (mg/L)	$6.1x10^{-5}$	0.450	-0.071	0.999	1.869	0.590
COD (mg/L)	$1.1x10^{-5}$	0.886	-0.001	0.999	-3.93	0.909
DO (mg/L)	-	-	0.024	0.999	-0.048	0.310
NO_3-N (mg/L)	0.022	0.489	-185.24	0.818	-0.098	0.779
Phosphate (mg/L)	0.002	0.729	-1.481	0.999	-0.021	0.826
Sulphate (mg/L)	0.003	0.870	-2.891	0.994	-0.096	0.962
Pb (mg/L)	0.0004	0.909	-313.7	0.926	-0.011	0.957

R^2 = Regression correlation coefficient

The values of K_1 and R^2 for the Pseudo-First order model were obtained as slope and correlation coefficient from a plot of q_e - q_t against time (Figs. 1 - 4), while K_2 and R^2 for the Pseudo-Second order model were obtained as slope and correlation coefficient from a plot of t/q_t against time (Figs. 5 - 7). The values of K_{int} and R^2 for Interparticle diffusion were obtained as slope and correlation coefficient from a plot of q_t against $t^{½}$ (Figs. 8 - 11).

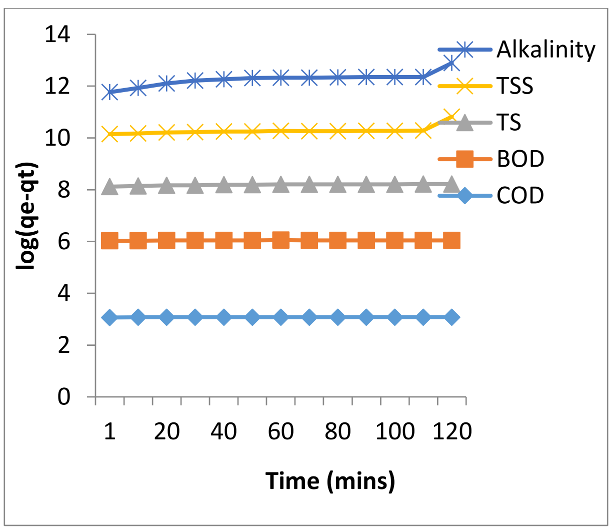

Figure 1: Pseudo-First order profile for the treatment of food industry wastewater (Alkalinity, TSS, TS, BOD, COD)

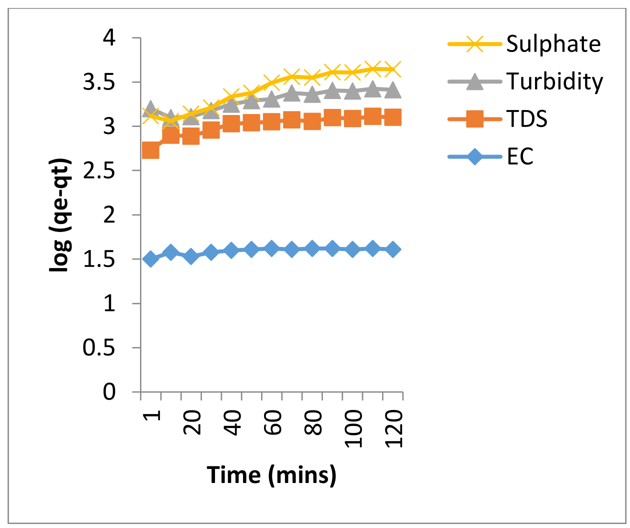

Figure 2: Pseudo-First order profile for the treatment of food industry wastewater (PO_4, Turbidity, TDS, EC)

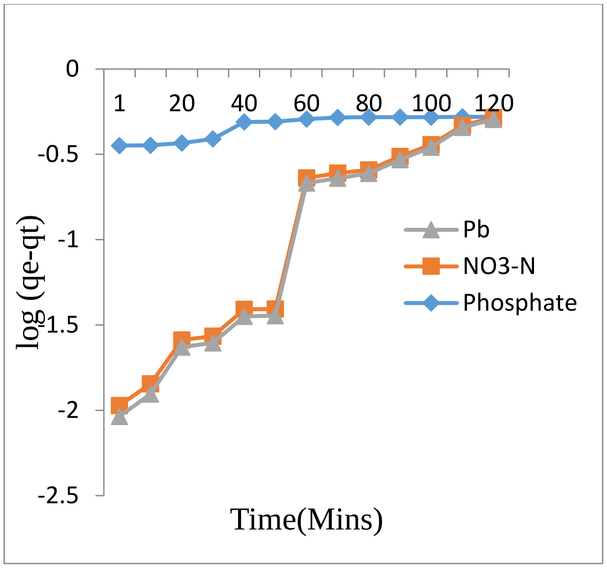

Figure 3: Pseudo-First order profile for the treatment of food industry wastewater (Pb, NO_3-N, PO_4)

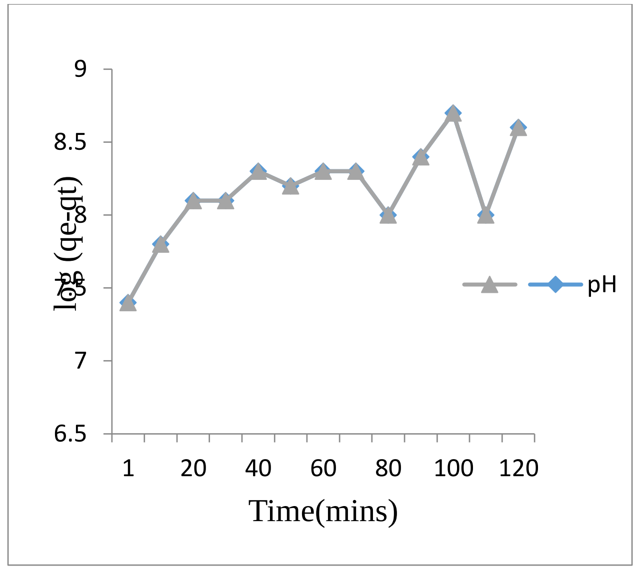

Figure 4: Pseudo-First order profile for the treatment of food industry wastewater (pH)

It is observed from Table 3 above that the treatment process using snail shell as adsorbent did not fit into the Pseudo-First-order kinetics, as poor linearity was observed in their correlation coefficient values (R^2) for all studied parameters when compared to the other models. This can further be seen in the kinetics plots of the linearised form of the Pseudo-First order model as shown in Figs. (1 - 4) above. The Pseudo-First-order kinetics of DO could not be determined, because the dissolved oxygen in wastewater was in gaseous form with its adsorption on powdered snail shell. The correlation coefficient (R^2) values of most of the parameters were 0.999, except TS, TDS, TSS, NO_3-N, Sulphate, and Pb with values of 0.997, 0.998, 0.770, 0.818, 0.994, and 0.926 respectively; when the results were subjected to Pseudo-Second order kinetics as seen in Table 3 and shown in Figs. (5 - 7) below:

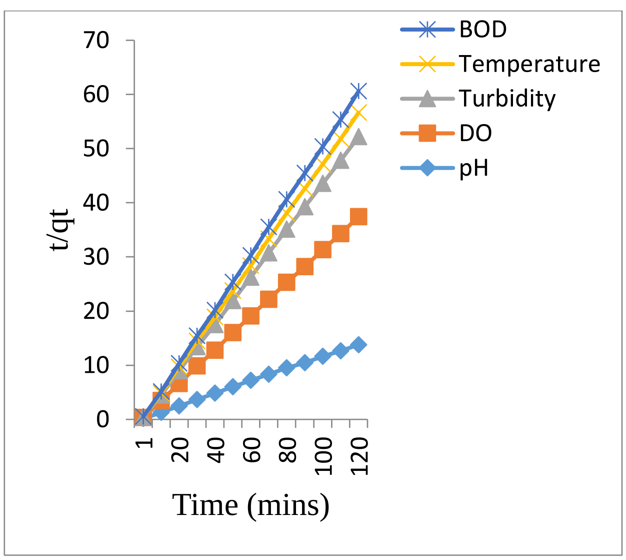

Figure 5: Pseudo-Second order profile for the treatment of food industry wastewater (BOD, Temperature, Turbidity, DO, pH)

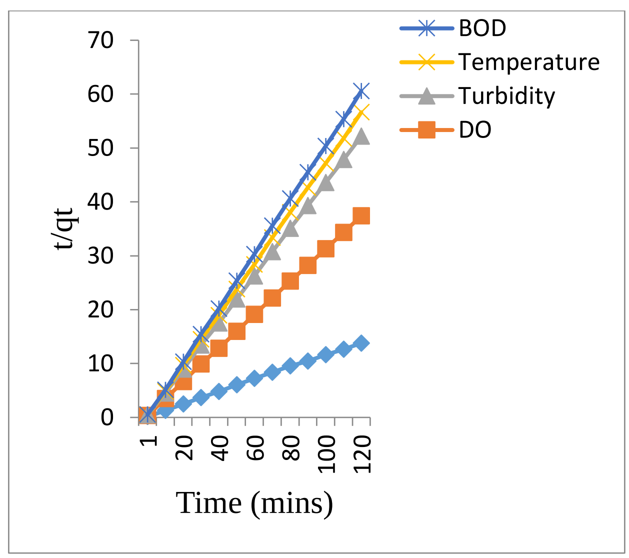

Figure 6: Pseudo-Second order profile for the treatment of food industry wastewater (Alkalinity, TDS, TS, EC, COD)

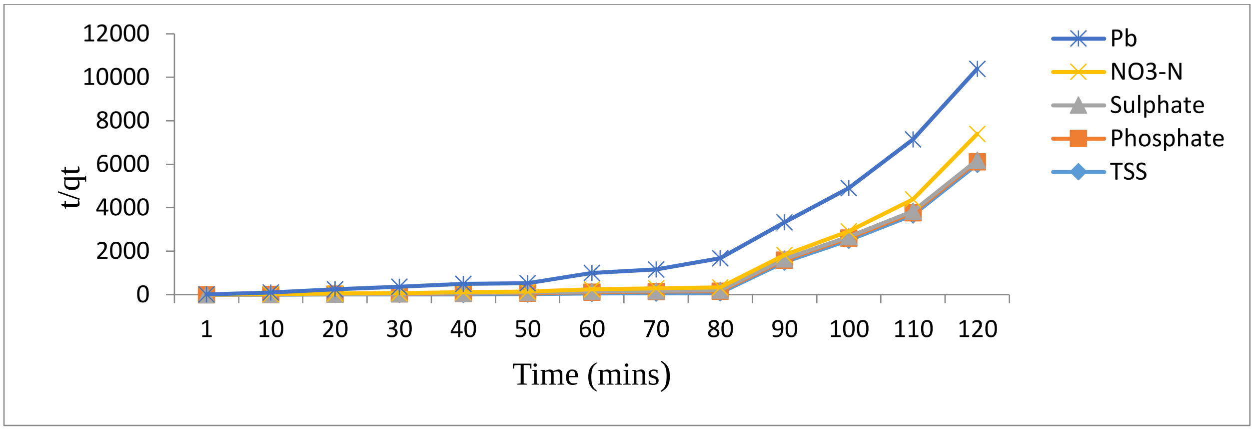

Figure 7: Pseudo-Second order profile for the treatment of food industry wastewater (Pb, NO_3-N, PO_4, TSS, SO_4)

The profiles observed (Figs. 5 - 7) shows that the Pseudo-Second order reaction rate model adequately describes the treatment of wastewater from the food industry using powdered snail shells, due to the good linearity and near unity value of their correlation coefficients. It further implies that the Pseudo-Second order adsorption mechanism was predominant, and the overall rate of the adsorption process appeared to be controlled by the chemical process, as previously observed by Hubbe *et al.,* [19]. The chemically controlled process could be by chemisorption, an adsorption process where most of the solid wastes that are polar bind with the ions on the surface of the powdered snail shell, where they are trapped. A similar phenomenon has been observed in the adsorption of remazol black B on biomass [20], adsorption of congo red [21], and 2-chloro-phenol on coir pitch carbon [22].

The observed kinetics is also supported by the findings of Jatto *et al.* [7], where similar Pseudo-Second order kinetics was reported for the treatment of brewery wastewater using snail shells, but with a different treatment approach. It can be observed from Table 3 that the treatment did not fit into the Intra-particle diffusion model, as the correlation coefficient (R^2) values of most of the parameters were out of linearity. The value of K_{int} is obtained as the slope of the plot of q_t against $t^{1/2}$, and the R^2 value is calculated from the graph as shown in Figs. 8-11 below.

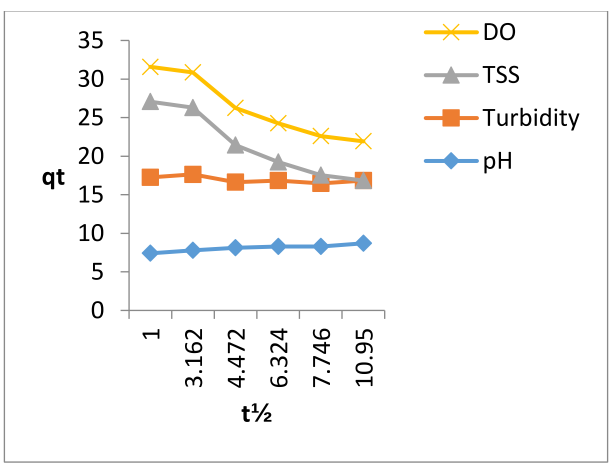

Figure 8: Intra-particle adsorption kinetics for the treatment of food industry wastewater (DO, TSS, pH, Turbidity)

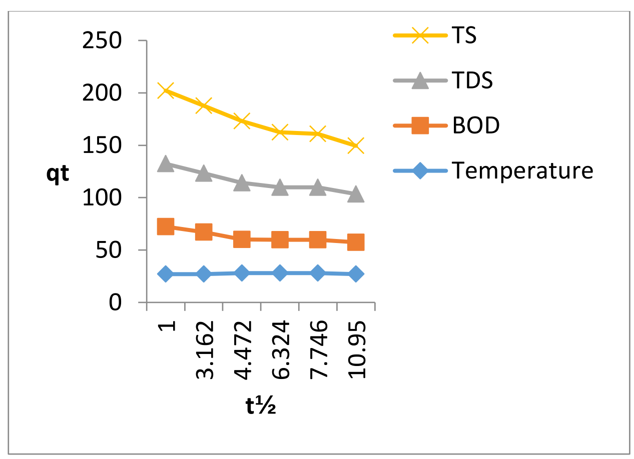

Figure 9: Intra-particle diffusion adsorption kinetics for the treatment of food industry wastewater (TS, TDS, BOD, Temperature)

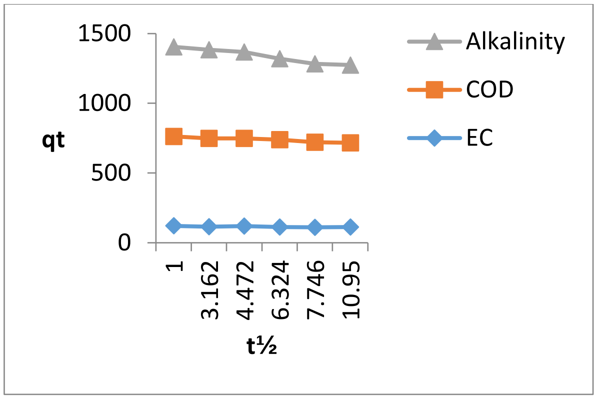

Figure 10: Intra-particle diffusion adsorption kinetics for the treatment of food industry wastewater (Alkalinity, COD, pH, EC)

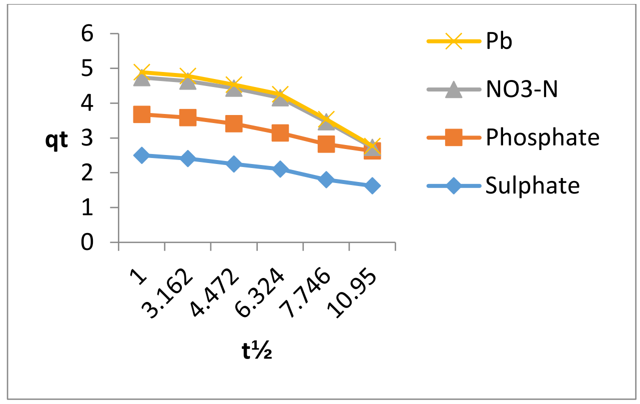

Figure 11: Intra-particle diffusion adsorption kinetics for the treatment of food industry wastewater (Pb, NO_3-N, SO_4 PO_4)

The treatment kinetics for TSS and Pb showed characteristics of Intra-particle diffusion, as near unity values were found for their R^2 (Table 3, Fig. 7 and 10). Any process that gives Intra-particle diffusion adsorption kinetics must show good linearity in its observed Intra-particle diffusion adsorption kinetics profile and near unity value of its regression correlation coefficient (R^2). Therefore, Intra-particle diffusion may be taken as their rate-determining step. These conditions have been reported to be characteristics of Intra-particle diffusion adsorption kinetics [23], with a multi-linear plot indicating that two or more steps influence the adsorption. However, the removal of Pb as an ionic contaminant by the adsorbent may be controlled by both a surface chemical adsorption process (chemisorption) and Intra-particle diffusion. Therefore intra-particle diffusion may be involved but may not be the only rate-limiting mechanism [24].

4.0 CONCLUSION

The use of snail shells for the treatment of wastewater obtained from a local food processing industry was investigated. The results show that the treatment was more effective as the treatment time increased, bringing about the influence of contact time in the treatment efficiency of the snail shell adsorbent. The results of this study demonstrate the efficacy of powdered snail shell as a cost-effective adsorbent and green remediation material in treating wastewater from the food industry. The kinetics observed for the treatment process for all water quality parameters provides insightful information and knowledge in understanding the adsorption mechanism of snail shell as a bio-adsorbent. Snail shells have therefore shown potential as a green adsorbent in the effective treatment of wastewater from not only food industry effluents, but wastewater

effluents from industries in general. Its applicability in this regard is hereby recommended for further investigation.

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REFERENCES

[1] Etsuyankpa, M.B., Augustine, A.U., Musa, S. T., Mathew, J. T., Ismail, H., Salihu, A. M., & Mamman, A. (2024). An overview of wastewater characteristics, treatment and disposal: A Review. *Journal of Applied Sciences and Environmental Management*, 28 (5) 1553-1572. DOI: https://dx.doi.org/10.4314/jasem.v28i5.28.

[2] Shivani, G., & Smita, C. (2017). Treatment of wastewater from food industry by membrane bioreactor. *International Advanced Research Journal in Science, Engineering and Technology,* 4 (6), 153-156. DOI: 10.17148/IARJSET.2017.4628.

[3] Lugo-Arias, J., Vargas, S. B., Maturana, A., González-Álvarez, J., Lugo-Arias, E., & Rico, H. (2024). Nutrient removal from aqueous solutions using biosorbents derived from rice and corn husk residues: A Systematic review from the environmental management perspective. *Water*, *16* (11), 1543. https://doi.org/10.3390/w16111543.

[4] Singh, S., Sharma, A., & Malviya, A. (2021.) Industrial wastewater: Health concern and treatment strategies *The Open Biology Journal,* 9, Tobioj-9-1. DOI: 10.2174/1874196702109010001

[5] Pankaj, B., Samiksha, J., Gulsum, M.U.B, Priyanka, K., & Halis, S. (2023). Developments and application of chitosan-based adsorbents for wastewater treatments. *Environmental Research*, 226,https://doi.org/10.1016/j.envres.2023.115530

[6] Gadzama, I. M. K., Ezealor, A.U., Aken'Ova, T., & Balarabe, M. L. (2017). Composition and distribution of terrestrial molluscs in relation to soil calcium and pH levels in parts of northern Nigeria. *The Zoologist*, 15: 35-42. http://dx.doi.org/10.4314/tzool.v15i1.6.

[7] Jatto, E.O., Asia, I.O., Egharevba, F., & Ewansiha, C.J. (2020). Kinetics studies of the treatment of wastewater from brewery industry, using powdered

snail shell, *Water-Energy Nexus*, 3, 95-102. https://doi.org/10.1016/j.wen.2020.06.001.

[8] Rice, E.W., Baird, R.B., & Eaton, A.D. (2017). Standard Methods for the Examination of Water and Wastewater, 23rd Edition, Publisher: American Public Health Association, American Water Works Association, Water Environment Federation. ISBN: 9780875532875 9. https://doi.org/10.1016/j-jhazmat 2020.122156 .

[9] Moussout H., Alilafi, H., Aazza, M., & Maghat, H. (2018). Critical of linear and non-linear equations of Pseudo-First order and Pseudo-Second order kinetic models. *Karbala international journal of modern Science*, 4(2) 244-254. https://doi.org/10.1016/j.kijoms2018.04.001.

[10] Ranawera, K., Godakumbura, P., & Perera, B. (2020). Adsorption removal of CO(II) in aqueous solutions using cheering nut seed powder. *Helyon,* 6(4) 1-9. https://doi.org/10.1016/j.helyon2020.e03684.

[11] Bujdak J (2020). Adsorption kinetic models in clay systems. The critical analysis of pseudo second order mechanism. *Applied clay science,* 191.105630. https://doi.org/10.1016/j.clay2020.105630 13.

[12] Chong, S. (2012), Performance Enhancements of upflow anaerobic sludge blanket reactors for domestic sludge treatment – A state of the art review. *Water research*, 46, 3434-3470. https://doi.org/10.1016/j.watres.2012.03.066.

[13] WHO, (2011) Chemical aspects. In: Guidelines for Drinking water Quality. fourth ed. W.H.O. Library Cataloguing-in-Publication Data, p. 177 http://news.xinhuanet.com/english/2010/health/2 011-07/04c_13965255.htm.

[14] Gerheart, W. A., Edward, E. K., Boansi, A. A., Elliot, A. Y., & Godfred, A., (2025). Pollution profiling and quality assessment of Bonsa River, Tarkwa Nsuaem, Ghana; Toxic element, Ecotoxicology, Health risk assessment, and Multivariate analysis. *Environmental Challenges*, 101078. https://doi.org/10.1016/j.envc.2024.101078.

[15] FME. (1991). Federal Ministry of Environment (Formally Federal Environmental Protection Agency, FEPA). Guidelines and Standards for Water and Industrial Waste Management in Nigeria, pp.46-55

[16] FEPA. (1991). Federal Environmental Protection Agency guidelines and standards for industrial waste management in Nigeria. pp 46-55.

[17] Nyilimbabazi, N., Bonadda, N., Naapi, I., & Wali, W.C. (2011). Characterization of brewery wastewater for reuse in Kigali, Rwanda. *The Open Environmental Engineering Journal,* 4, 89-96. DOI: 10.2174/1874829501104010089.

[18] Kolhe, A.S., Ingale, S.R., & Sarode, A.G. (2008). Physicochemical analysis of sugar mill effluents. *International Research Journal,* 4 (1), 307-311.

[19] Hubbe, M. A., Azizian, S., & Douven, S. (2019). Implications of apparent pseudo-second-order adsorption kinetics onto cellulosic materials: A review. *BioResources*, 14(3), 7582-7626. DOI: 10.15376/biores.14.3.7582-7626.

[20] Aksu, Z., & Tezer, S. (2005). Biosorption of reactive dyes on the green algae chlorella vulgaris. *Process Biochemistry,* 40 (3-4), 1347-1361. https://doi.org/10.1016/j.procbio.2004.06.007.

[21] Namasivayam, C., & Kavitha, D.(2002). Removal of Congo Red from Water by Adsorption onto Activated Carbon Prepared from Coir Pith, an Agricultural Solid Waste. Dyes and Pigments, 54, 47-58.http://dx.doi.org/10.1016/S0143-7208(02)00025-6.

[22] Namasivayam, C., & Kavith, D. (2005). Adsorptive removal of 2,4- dichlorophenol from an aqueous solution by low-cost carbon from an agricultural solid waste: *coconut coir pith. Separation Science and Technology,* 39(6), 1407-1425. DOI: 10.1081/SS-120030490.

[23] Marques, T., Vanessa, N. A., Luciana, M. C., & Nivia, M. M. C. (2013). Assessment of the use Moringa Oleifera Seed fors for the Removal of Manganese ions from aqueous System. *BioResources,* 8 (2) 2738-2751. DOI: 10.15376/biores.8.2.2738-2751.

[24] Bansode, J.N., Losso, W.E., Marshall, R.M., & Rao, R.J. (2004). Pecan shell-based granular activated carbon for treatment of chemical oxygen demand (COD) in municipal wastewater, *Bioresource Technology, 94, 129–135.* https://doi.org/10.1016/j.biortech.2003.12.009