Thermodynamic Studies of the treatment of wastewater from brewery industry using powdered snail shell

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ABSTRACT

Thermodynamic studies of the treatment of wastewater from brewery industry were carried out. The change in standard Gibb's free energy (ΔG^o) for pH were 0.71, 0.72, 0.45 and 0.49 kj/mol, while for dissolved oxygen were 0.93, 0.96, 0.98, 0.97 and 0.95 kj/mol.K The values of change in standard entropy (ΔS^o) and standard enthalpy (ΔH^o) were -1.21 and 542.5 kj/mol.K respectively. Other parameters of the wastewater had negative values of change in standard Gibb's free energy (ΔG^o), among which were alkalinity with values of -1.13, -048, -0.94, -0.70 and -0.73 kj/mol. Turbidity had values of ΔG^o as -2.62, -1.82, -1.87, -1.78 and -1.76 kj/mol, while electrical conductivity values were -2.12, -2.17, -2.23, -2.20 and -2.23 kj/mol. Total solids had values of ΔG^o as -0.41, -0.39, -0.38, -0.38 and -0.32 kj/mol, while biochemical oxygen demand values were -0.39, -0.37, -0.33, - 0.24 and -0.19 kj/mol, values of ΔG^o for chemical oxygen demand were -0.68, -0.66, -0.64, -0.62 and -0.65 kj/mol, nitrate-nitrogen had values of -0.95, -0.88, -0.87, -0.86 and -0.87 kj/mol. ΔG^o for phosphate were -5.42, -5.52, -5.62, -5.78 and -6.09 kj/mol; for sulphate the values were -9.42, -9.42, -9.89, -10.14 and -10.60 kj/mol. The values of change in standard entropy (ΔS^o) was negative for most parameters with the exception of turbidity, total solids and biochemical oxygen demand and change in standard enthalpy (ΔH^o) was positive for electrical conductivity, total suspended solid, phosphate and sulphate, but negative for other parameters. This showed that the reduction of most parameters during treatment at different temperature was spontaneous, except for pH and dissolved oxygen that have positive values for standard Gibb's free energy.

Keywords: *Treatment; Wastewater; Snail shell; Thermodynamic studies; Brewery industry.*

INTRODUCTION

Many methods are available for the treatment of wastewater to produce an environmentally safe- fluid waste stream, or treated effluent and solid waste or treated sludge that can be reused or safe for disposal (Desitti *et al.*, 2011).

In general, there are various technological methods existing for the treatment of wastewater, such as chemical precipitation, ion exchange, adsorption, membrane processes, supercritical fluid extraction, bioremediation and oxidation with oxidizing agent (Asia and Oladoja, 2007).

However, most of these technologies are either extremely expensive or too inefficient in the treatment of water and wastewater. Biosorption, a process whereby certain types of inactive dead biomass (such as snail shell, peat, rice husk, fruit peels) may bind and concentrate heavy metals from aqueous solution is considered as an alternative technology for the removal of heavy metals and other pollutants from wastewater and industrial effluent (Volesky, 2003; Naja, and Mustin, 2005). Efficient and environment friendly methods are thus needed to be developed; biosorption technology is advantageous due to the cost effectiveness of biosorbent (biomass) since they are derived from cheap sources.

Thermodynamic studies

Thermodynamic is the study of energy changes accompanying physical and chemical changes, and subsequently the macroscopic variables such as temperature, volume and pressure. The starting points for most thermodynamic considerations are the laws of thermodynamics, which postulates that energy can exchange between physical system as heat or work (Valeria *et al.*, 2008). The existence of a quantity known as the entropy was also postulated, which can be defined for any isolated system in thermodynamics equilibrium (Tan, *et al.*, 2008).

The thermodynamics parameters such as change in standard Gibb's free energy (ΔG^o), standard enthalpy (ΔH^o) and standard entropy (ΔS^o) can be determined using the following equations:

$$\ln k_c = \frac{\Delta S^0}{R} - \frac{\Delta H^0}{RT} \quad \text{......... (1)}$$

$$\Delta G_{ads} = \Delta H_{ads} - T\Delta S_{ads} \quad \text{......... (2)}$$

Where R (8.314 $jmol^{-1}K^{-1}$) is the gas constant, T is the absolute temperature and K_c(l/g) is the standard thermodynamic equilibrium constants defined by q_e/c_e, by plotting a graph of $\ln K_c$ versus 1/T and the values of ΔH^o and ΔS^o estimated from the slope and the intercept.

Contrast to the study of adsorption using activated carbon and different agricultural and animal bye products, the study of snail shell as an adsorbent is scarce, and thermodynamic study of the treatment using this animal product is new. The snail shell cell wall is built in different layers each with a special purpose and built by a different cell layers (Aboua, 1995). The main shell layer which consist of a hard mineral aragonite ($CaCO_3$) is mechanically very hard and was very susceptible to chemical corrosion, on the other hand the skin shell though mechanically weak was quite unsusceptible to chemical corrosion, hence protected the shell layer (Poppe and Tagoro, 2006).

This work focuses on the treatment of wastewater from brewery industry at different temperature, using adsorption method on waste substances such as snail shell, to reduce the waste or pollutant from the wastewater at the minimum expense of energy.

Brewery industry generates large amount of wastewater originating from the various process units. The wastewater is high in carbohydrate, nitrogen and detergents generated from the cleaning and washing reagents, these have been proven as water pollutants (Kanu and Achi, 2011). The introduction of wastewater high in organic matters and essential nutrients brings about changes in microflora and this will lead to high demand of dissolved oxygen, which will eventually lead to reduction in dissolved oxygen leading to water pollution, hence the treatment.

MATERIALS AND METHOD

Collection of snail shell

Four different species of snail shell (*Archatina archatina, Archatina maginata, Archatina fulica, Limucularia*) were collected from the environment within Ekpoma Edo state of Nigeria. The shells were washed with hot water to remove sand and dirt, it was then sun dried.

Analysis of snail shell

The snail shells were pulverized and sieved using a sieve of 0.5 µm pore size to obtain a fine powder. Stability test was carried out on the snail shell powder to know the pH at which it will dissolve in acid or alkali medium; this was achieved by preparing acid solution using1M

CH_3COOH and alkali solution using 0.5M NaOH (Pearson, 1976). The BET (Brunauer-Emmet-Teller) surface area of the powdered snail shell was obtained from nitrogen gas adsorption following method adopted by (Brunauer *et al.,* 1938).

Sampling technique

The wastewater was collected at discharge point into the river at once (grab sampling method). The container for the collection of wastewater was properly washed with water to remove any dirt, it was allowed to dry and some quantity of Manganeous sulphate salt was poured into the container, this was to fix the dissolved oxygen, since its determination was not carried out on site during collection.

Analysis of wastewater

All analyses were carried out on the wastewater in triplicate to ensure representative and reproducible results and obtain data for statistical analysis. pH and temperature were determine on site and the wastewater was preserved at a temperature of 4°C in a refrigerator for more analysis. Heavy metals were analysed using atomic absorption spectrophotometer (AAS) (Bulk scientific model 210 VGP) after digestion following procedures adopted by (Burguera *et al.,* 1986). Other physicochemical analyses of the sample were carried out as describe in the standard methods for the examination of water and wastewater APHA (1998) and standard methods for water and effluent analysis (Ademoroti, 1996).

Thermodynamic study

Calculated amount (10 g) of powdered snail shell was weighed and poured into a 250 mL beaker containing 100 mL of wastewater. The beaker was placed inside another 500 mL beaker containing ice mixture to maintain the temperature at 283 K; the mixture was stirred mechanically at regular interval for 1 hour and then filtered. Physicochemical analyses were carried out on the filtrate using standard methods (Ademoroti, 1996; APHA, 1998).

The process was repeated at different temperature: 293 K, 303 K, 313 K and 323 K. The temperature was raised by applying heat, using water bath.

RESULTS AND DISCUSSION

The pH value of snail shell powder in solution was 8.84, which showed that its solution was alkaline, which may have resulted from the presence of calcium carbonate and protein as some of the composition of the shell (Aboua, 1995). It was easy to pulverize the snail shell into fine powder. The BET studies of the powdered snail shell gave a large surface area of 40.29 m^2/g; hence it serves as a good adsorbent for the removal of pollutants from wastewater.

Treatment of wastewater at different temperatures

The physicochemical analysis of wastewater from brewery at different temperature is presented in Table 1 below.

Table 1: Treatment of wastewater from brewery at different temperatures

S/N	Parameter	Unit	FMES (2003)	Untreated wastewater	Temperature (K)				
					283	293	303	313	323
1	pH		6.5-8.5	6.44±0.9	8.7	8.6	7.7	7.6	7.7
2	Alkalinity	mg/L		262.7±2.0	162±0.5	168±0.2	180±0.5	200±0.4	201±0.4
3	Turbidity	NTU	50	317±1.0	104±1.6	150±1.4	151±1.5	160±1.5	168±1.3
4	Electrical conductivity (EC)	µS/cm	100	689±1.0	280±1.2	283±1.5	284±1.4	296±1.3	308±1.5
5	Total solids (TS)	mg/L		388.01±3.0	326±0.6	331±0.6	334±0.8	334±0.5	346±0.6
6	Total suspended solids (TSS)	mg/L	50	10.23±2.0	0.6±0.1	0.62±0.2	0.64±0.2	0.66±0.5	0.7±0.3
7	Total dissolved solids (TDS)	mg/L	250	382.3±2.0	325.40±4.6	330.38±4.5	333.36±5.0	333.34±4.3	335.3±4.0
8	Biochemical oxygen demand (BOD)	mg/L	40	16.9±0.6	14.3±2.0	14.5±2.5	14.8±2.4	15.4±2.4	15.8±2.5
9	Chemical oxygen demand (COD)	mg/L		348.05±2.0	260.81±2.0	265.83±2.1	270.24±2.1	274.30±1.7	275.10±1.7
10	Dissolved oxygen(DO)	mg/L	>4.0	4.75±0.1	5.06±0.1	4.03±0.1	4.00±0.15	2.90±0.23	2.70±0.31
11	Nitrate-nitrogen (NO_3-N)	mg/L	40	0.961±0.3	0.64±0.01	0.67±0.01	0.68±0.02	0.69±0.02	0.70±0.01
12	Phosphate	mg/L	5	0.83±0.2	0.083±1.2	0.086±1.4	0.089±1.2	0.09±1.3	0.092±1.4
13	Sulphate	mg/L	240	3.40±0.2	0.062±0.62	0.062±0.61	0.067±0.56	0.069±0.56	0.07±0.61
14	Pb	mg/L	0.05	0.168±0.3	BDL	BDL	0.001±0.02	0.0015±0.04	0.002±0.02
15	Cd	mg/L	0.05	0.01±0.0001	BDL	BDL	BDL	BDL	BDL

- BDL: Below detected limit.

The pH of the treated wastewater at 283K was 8.7, it was higher than that of the untreated wastewater was 6.44 (Table 1), and there was slight decrease as the temperature of treatment increases. The reason for this slight decrease, results from the dissociation of inorganic and organic substances into ions at high temperature (Ekhaise and Anyasi, 2005). The allowable pH value range for wastewater discharge into the environment should vary between 6.5 and 8.5 (FMES, 2003). The pH value in this study may not have much effect on the aquatic organism in the river. The reason for this pH value which is close to neutrality is due to the presence of organic matter in the brewery waste which can serve as a buffer in the solution (Tan, 1993). Liquors pressed from grains and yeast recovery, form the composition of wastewater from brewery industry which gives it the characteristic odour of fermented malt and its slight acidity (Kanu *et al.*, 2006).

The temperature of the untreated wastewater from brewery was 26.9±0.10°C. Temperature is important in wastewater treatment due to its effects on certain chemical and biological reactions that take place in water and in organism inhabiting the habitat. Measurement of temperature is an important parameter used to determine the self purification capacity of rivers, reservoir and control of treatment plant (Babarinde and Babalola, 2010).

The temperature of water is also important for aquatic life; it is also an important parameter for calculating the solubility of oxygen, carbon (IV) oxide, bicarbonates and carbonates (Ademoroti, 1996). The taste of wastewater is determined by the temperature of the wastewater. The temperature of water is affected by variables such as the colour of water, the depth of water, the amount of shade received from shoreline vegetation, latitude of water, volume of water, temperature of effluents dumped into the water (Jatto and Asia, 2010), when this wastewater is discharged into the nearby river it will not increase the temperature of the receptive water body. The value of the temperature is within the FMES (2003) limit of 35°C. Increase in temperature leads to decrease in dissolved oxygen.

Fishes and other marine organism use more oxygen at higher temperature due to increase in their metabolic activities, since they are cold-blooded animals (Burne, 1987).

The same trend of increase in other parameters was observed as the temperature of treatment increases with exception of dissolved oxygen that decreases with increase in temperature.

Dissolved oxygen, is one of the parameters in water quality assessment, its presence is important to maintain a variety of forms of biological life in water. The effects of wastewater discharged in the water body are largely determined by oxygen balance of the system. Wastewater from brewery contains high oxygen consuming matters hence the values of the dissolved oxygen in the brewery wastewater in this study was 4.75±0.10 mg/L. Most fishes require at least 5 mg/L dissolved oxygen for at least 16 hours. Avsan and Rao, (2001) observed that anoxic conditions can occur in fishes when the dissolved oxygen of wastewater is low, this is a case of respiratory distress in fishes and under this condition they start showing erratic behaviours. Wastewater from brewery, in this study could cause the depletion of dissolved oxygen when discharged into water bodies. Ekhaise and Anyasi, (2005) reported high count of bacterial population at the receiving axis of the wastewater from brewery in Ikpoba river in Benin City. The introduction of wastewater high in organic matters and essential nutrients brings about changes in microflora and this also may lead to high demand of dissolved oxygen, which will eventually lead to reduction in dissolved oxygen, hence water pollution. There was also increase in microbial activities and increase in the oxidation of substances hence increase in the utilization of dissolved oxygen and subsequent reduction of dissolved oxygen as can be observed in Table 1.

The alkalinity value was 262.7±2 mg/L for the untreated wastewater. Alkalinity is a measure of the substances in water that have acid neutralizing ability (Linsley and Franzini, 1979). This value of alkalinity is as a result of some of the compositions of wastewater generated from brewery industries. The effluents are high in carbohydrate, nitrogen and detergents generated from the cleaning and washing reagents, these have been proven as water pollutants (Kanu and Achi, 2011). Alkalinity is important for fishes and aquatic life because it buffers against pH changes and make water less vulnerable to acid rain. The value of alkalinity obtained during treatment at different temperatures was less than that of the untreated wastewater; the value was 162±0.5 mg/L at 283 K which increased as the temperature increased, this increase in alkalinity at increased temperature resulted from the ionisation of compounds at high temperature.

There was reduction in electrical conductivity after treatment of the wastewater from brewery, at 283 K, but the values increased as the temperature increased. The reason was that at high temperature, there was high degree of ionization, high mobility of Ions which led to increase in the electrical conductivity.

The turbidity value of 317±1.0 NTU showed that the colloidal materials were high as compared to FMES value of 0 to 1 NTU. This was an indication of the turbid nature of the water and by implication it showed that the wastewater was high in the total solid content, which comprised of dissolved and suspended solids. Turbidity is not a major health concern, but high turbidity can interfere with disinfection and provides a medium for microbial growth. It can also indicate the presence of microbes (Buzzini and Pires, 2007).

The total solid for the untreated wastewater was high (388.01±3.0 mg/L) compared with values obtained at different treatment temperatures (Table 2). The term total solids refer to the matters either filterable or unfilterable that remain as residue upon evaporation and subsequent drying at a defined temperature employed for drying and ignition (Kolhe and Pawar, 2011).

The BOD value of the wastewater shows that it contains biological materials that deplete dissolved oxygen in water. The biochemical oxygen demand of the untreated wastewater was 16.9±0.3 mg/L. It may not too toxic but it is objectionable to aquatic organism when the concentration is high. The maximum allowable limit of Biochemical oxygen demand into the river is 40.0 mg/L (FMES, 2003). The value of the Chemical Oxygen Demand (COD) in this study was high when compared to FMES limit of 80 mg/L (FMES, 2003). This is an indication that the wastewater from brewery has a high pollution potentials, hence the need for treatment before reuse or safe discharge to the environment (Asia and Akporonor, 2007). The conductivity value of the untreated wastewater was 689±1 μScm^{-1}, and showed that the wastewater contained ions which suggest that physical and chemical methods can be employed in the treatment of the wastewater from brewery.

The value of nitrate nitrogen was high compared to FMES (2003) standard of 0.5 mg/L, this is as result of the high content of nitrogenous substances in brewery wastewater, because in the presence of oxygen, organic nitrogen and ammonia are converted to nitrate (Nyilimbabazi *et al*., 2011) and in the absence of oxygen the nitrate nitrogen is converted to nitrogen gas by the denitrifying bacteria which strip oxygen from the nitrate (Buchanan and Saebloom, 2004), hence the need to treat it before safe discharge or reuse.

Nitrogen in water can promote the growth of plants and algae leading to eutrophication and algae bloom; this can lead to depletion of dissolved oxygen hence pollution. Nitrate in water can result to metheamoglobamia in children when used to prepare food for children.

The phosphate level was 0.83 mg/L which as within the FMES (2003) standard. Phosphate is the chemical compounds containing the element phosphorus, which is necessary for plant and animal growth. This stimulates the growth of plankton, and water plants that provide food for fish, however, high amount of phosphate in water may lead to eutrophication and there will be increase in demand of the dissolved oxygen thereby polluting the water.

Phosphate does not have harmful effect on human and animals unless they are present in high concentration even then, they will probably do little more than interfere with digestion. The level of heavy metals analysed was 0.168±0.03 mg/L, and 0.008±0.01 mg/L, for Pb and Cd respectively. This showed that their levels were within FMES (2003) limits for safe discharge of industrial waste, however when these metals are constantly discharged into the river the concentration will increase and this can have harmful effect on human when the water is consumed.

Pb was not detected at 283 K and 293 K, but was detected at temperature of 303 K, 313 K and 323K, the values were 0.001 mg/L, 0.0015 mg/L and 0.002 mg/L respectively, and it was observed that there was increase in the values of Pb as the temperature increased. This suggested that the rate of adsorption was high at low temperature.

Thermodynamic study of treatment of wastewater from brewery industry

The results obtained from the treatment of wastewater from brewery industry at different temperature using powdered snail shell were subjected to thermodynamic studies using the Langmuir equation of $\Delta G = -RTlnK_{ad.}$ .Where ΔG^0 is the change in standard Gibb's free energy, R is the universal gas constant which is equal to ($8.314\ JK^{-1}mol^{-1}$), K_{ad} is the adsorption constant, and is $K_{ad} = q_e/q_t$. The changes in standard enthalpy (ΔH^O) and standard entropy (ΔS^O) were obtained from the slopes and intercepts respectively of the plot of ΔG^O against temperature as shown in Figures 1, 2 and 3.

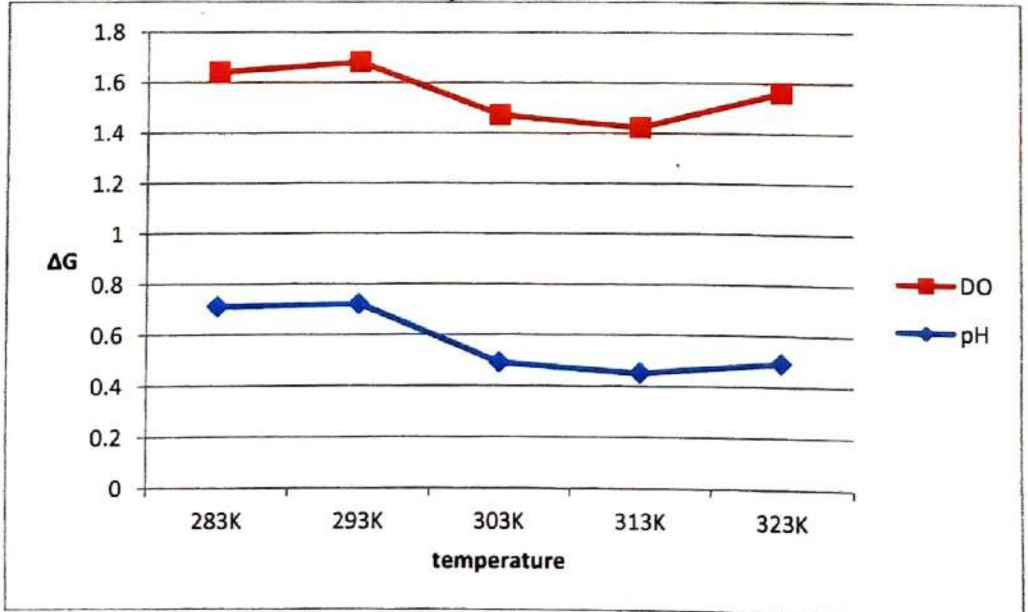

Figure 1: the plot of ΔG against temperature for DO and pH

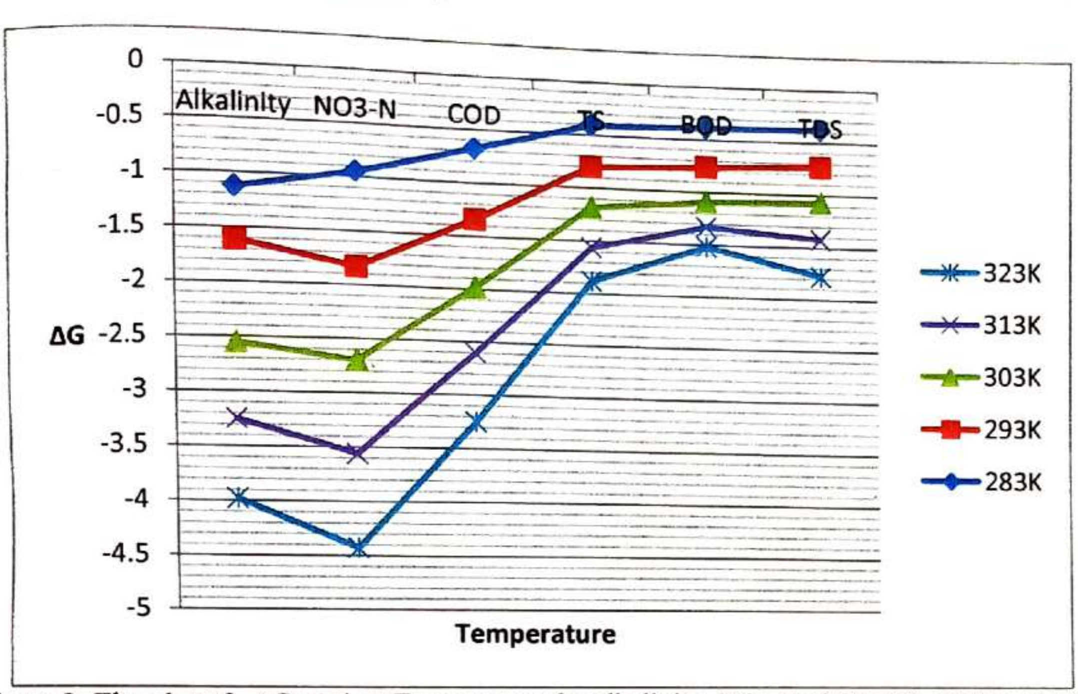

Figure 2: The plot of ΔG against Temperature for alkalinity, NO_3-N, COD, TS, BOD and TDS

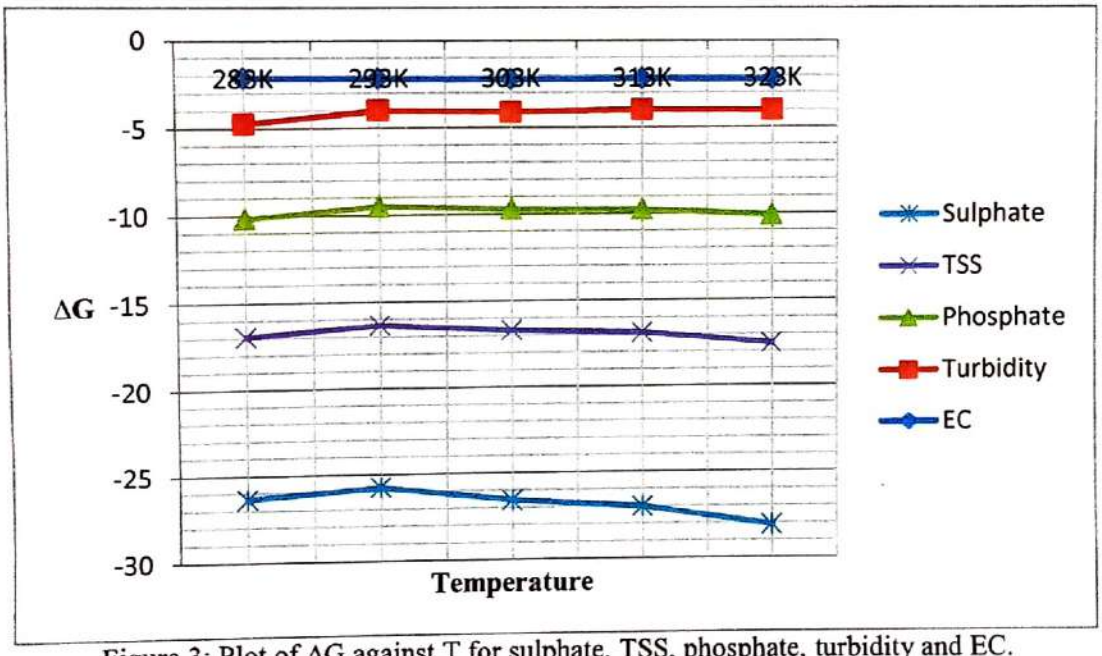

Figure 3: Plot of ΔG against T for sulphate, TSS, phosphate, turbidity and EC.

The thermodynamic data from the study are presented in the Table 2 below:

Table 2: Thermodynamic data of treatment of wastewater from brewery

Parameter	ΔG(Kj/mol)						ΔS (kj/mol.K)	ΔH (kj/mol)
	Temperature (K)	283	293	303	313	323		
pH		0.71	0.72	0.49	0.45	0.49	-1.21	542.5
Alkalinity		-1.13	-0.48	-0.94	-0.70	-0.73	-1.70	-748.9
Turbidity		-2.62	-1.82	-1.87	-1.78	-1.76	2.37	-1306.4
EC		-2.12	-2.17	-2.23	-2.20	-2.23	-2.82	193.7
TS		-0.41	-0.39	-0.38	-0.38	-0.32	0.17	-165.5
TSS		-6.77	-6.83	-6.98	-7.13	-7.43	-11.90	1481.06
TDS		-0.38	-0.35	-0.34	-0.35	-0.36	-0.29	-186.40
BOD		-0.39	-0.37	-0.33	-0.24	-0.19	1.15	-445.05
COD		-0.68	-0.66	-0.64	-0.62	-0.65	-0.03	-184.4
DO		0.93	0.96	0.98	0.97	0.95	1.07	-346.5
NO_3-N		-0.95	-0.88	-0.87	-0.86	-0.87	0.02	-272.8
Phosphate		-5.42	-5.52	-5.62	-5.78	-6.09	-10.06	1333.8
Sulphate		-9.42	-9.42	-9.89	-10.14	-10.60	-19.13	2807.6
Pb		NC	NC	-12.01	-12.28	-12.23	NC	NC
Cd		NC	NC	NC	NC	NC	NC	NC

□ NC: Not computed

From the Table 3, it was observed that the values of ΔG^o and ΔH^o were positive and ΔS^o was negative for pH, this is an indication that the pH determination was not spontaneous, it is an endothermic process and the process is not random, that is, it is stable (Babalola *et al*; 2009).
The positive value of ΔH^o shows that the pH determination in the treatment of wastewater from brewery using powdered snail shell was an endothermic process which was also consistent with decrease in the value of ΔG^o at increase in temperature (Babalola, *et al.;* 2009). This was also related to the decrease in adsorption with increase in temperature, the value of ΔS^o was negative which reflected the orderliness of the treatment process with respect to pH. This may be due to the weakening of adsorptive forces between the adsorbent and the adsorbate species and also between the adjacent molecules of the adsorbed phase (Pandey, *et al* 1986).

The negative values of ΔG^o, ΔH^o and ΔS^o for alkalinity, TDS and COD parameters indicated that their determination in wastewater from brewery were spontaneous, exothermic and random processes. Also the negative value of ΔS^o showed that the adsorption process in the treatment of wastewater from brewery was stable, and there was an increase in orderliness and decrease in the degree of freedom of adsorbed species in the treatment process, a confirmation that there is better adsorption at reduced temperature (Babalola, *et al.,* 2009). ΔG^O and ΔH^O were negative for turbidity, TS, BOD and NO_3-N and positive value of ΔS^O. The negative values of ΔG^O and ΔH^O indicated that the reduction of turbidity, TS, BOD and NO_3-N was spontaneous and exothermic when the wastewater from brewery was treated with powdered snail shell, while the positive value of ΔS^o indicated that the disorderliness of the reduction in the turbidity, TS and NO_3-N and the affinity of particles to the adsorbent.

It also suggested some structural adjustment of the powdered snail shell when in contact with this particle in wastewater. There is a relationship between this and the study reported by (Alzaydien and Manarsreh, 2009), on the adsorption of phenol on Activated phosphate rock (APR).

Dissolved oxygen had positive values of ΔG^o, ΔS^o and a negative value of ΔH^O. The positive value of ΔG^o reflected the decrease in the level of DO as the temperature of the system increased, hence the randomness of the dissolved oxygen at high temperature. It was observed from experiment that at increase in temperature, there was increase in the consumption of dissolved oxygen as result of increase in the metabolic activities of organism in the wastewater hence reduction in the volume of dissolved oxygen.

The thermodynamic studies of the treatment of wastewater provided a good platform for a better understanding of the temperature at which these parameters were reduced, which indicated that the level of pollution in wastewater was reduced, also the temperature at which there was optimum dissolved oxygen. From the thermodynamic studies it is discovered that the optimum value of dissolved oxygen is at reduced temperature, as indicated from the positive value of ΔG^o, which indicate that the increase in the volume of dissolved oxygen during treatment is not spontaneous at a high temperature hence resulting in the disorderliness of the dissolved oxygen as indicated by the positive value of ΔS^o and the negative value of ΔH^O which shows the exothermic nature of the treatment process as regard the optimum value of dissolved oxygen at reduced temperature.

The values of ΔG^o and ΔS^o are negative for phosphate and sulphate but they have a positive value of ΔH^o. This shows that their removal or reduction from wastewater during treatment is spontaneous and endothermic. The process of the adsorption of phosphate and sulphate on the adsorbent is energy consuming, this also confirm the possibility of chemical adsorption of these compounds from wastewater as the temperature increases, (Singh *et al.*, 2004), the negative values of ΔS^o correspond to a decrease in the degree of freedom of the adsorbent at a high temperature. A similar result is reported by (Zabihi *et al.,* 2010) in the thermodynamic studies of adsorption of Hg (ll) on wallnut shell powder. The values of ΔS^o and ΔH^o for Pb and Cd could not be computed because they were not detected at low temperature for Pb while that of Cd could not be detected at all the temperature. However the ΔG^o values of Pb (ll) ions were -12.01, -12.28 and -12.23 kj/mol at 303K, 313K and 323K respectively, which reflect the spontaneity of the treatment at increase in temperature during treatment process. The increase in the values of Pb (ll) ions indicates the decrease in adsorption of this metal at a high temperature.

Conclusions

The results of these studies showed that snail shell powder can be used effectively in the treatment of wastewater from brewery industries. There were reductions in the rate of adsorption and increase in the metabolic activities of substances in the water, which increased the consumption of dissolved oxygen as the temperature increases. The thermodynamic studies of the treatment of the wastewater revealed that the change in free energy (ΔG^o) for most of the physicochemical parameters has negative values. This confirms the feasibility of the treatment process and the spontaneous nature of the adsorption of the dissolved solid substance by the snail shell powder during treatment. There was also increase in the degree of ionization of solid substances in the wastewater at high temperature, which was evidence from the positive value of the change in free energy (ΔG^o) of pH of the treated wastewater. This research showed that adsorption as a treatment option of wastewater was more effective at low temperature.

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