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FACTORIAL ANALYSES, EQUILIBRIUM STUDIES, KINETICS AND THERMODYNAMICS OF THE REMOVAL OF SUSPENDED PARTICLES FROM AN INDUSTRIAL EFFLUENT ON COAL BASED ACTIVATED CARBON

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ABSTRACT

Batch adsorption has been used to study the adsorption performance of coal based activated carbon (COBAC) in a fibre-cement effluent (FCE) at room temperature and pH of 12. This paper demonstrates the use of analysis of variance (ANOVA) and Fisher's least significant difference statistics in the determination of the adsorption performance of COBAC at varying time and various dosages. Increasing COBAC dosage and adsorption time respectively, had high significant differences on the adsorption performance of COBAC. In addition, time/dosage interactions had significant difference on COBAC adsorption performance. Adsorption dynamics studies show that 'animekus' expression for pseudo second order kinetic model gave the best predicted adsorption capacity values and as such, favours chemisorption mechanism. Thermodynamic studies reveal effective adsorption of suspended solids onto COBAC. Equilibrium studies revealed that adsorption data of suspended particles onto COBAC followed Langmuir pattern reaffirming chemisorption adsorption mechanism.

Keywords: Factorial optimization, Industrial effluent, Kinetic models, Batch adsorption, Total suspended solids.

INTRODUCTION

The major components of our environment are the air, water and land. These components of our environment are under serious threat of pollution from the activities of man. One of such activities of man is the production of effluents from industrial activities, and they are discharged into the surrounding lands and rivers/streams. The indiscriminate discharge of industrial effluents into surrounding lands and rivers pose adverse effects on man, animals and vegetation, and as such requires treatment to reduce the discharged effluents to save/tolerable levels.

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Over the past few decades, sorption has gained importance as an effective purification and separation technique used in wastewater treatments[1]. In this work, the potentials of activated carbon prepared from coal for the removal of colloids from aqueous solution has been studied.

Coal based activated carbon (COBAC) has the potential to function as an adsorbent. The removal of turbidity from a fibre-cement effluent using COBAC has been studied to evaluate the kinetics of turbidity removal. Furthermore, COBAC turbidity removal capacity was studied using two-way factorial analyses to analyse the variances of our experimentally obtained data such that the effects of COBAC dosage, adsorption time variation and dosage/time interaction were determined.

Analysis of variance (ANOVA) is one of the commonly used statistical techniques to compare several groups[2]. It is appropriate for testing the significant difference among k-population means simultaneously and without altering the probability of making type one error[3]. Factorial analyses are useful in research because, the effects of more than one factor can be studied in a single experiment[4].

Therefore, this paper aims to reveal; the effects of time, adsorbent dosage and time/adsorbent dosage interactions on adsorbent performance of COBAC; the optimum time for COBAC adsorption performance; the optimum COBAC dosage for COBAC adsorption performance; and the kinetics of adsorption of suspended particles unto COBAC.

Materials and methods

The collection of fibre-cement industry effluent

The effluent sample used in this investigation was collected from the effluent channel of fibre-cement industry located at Emene, Enugu State of Nigeria. The effluent was stored in black plastic jerry can to prevent variations in the characteristics of the effluent. The physiochemical properties of the effluent shown in Table 1 were determined based on standard methods described elsewhere[5].

Adsorbent preparation

The precursor for the preparation of the activated carbon was taken from Enugu coal mines, Enugu State of Nigeria. The prepared coal of particle sizes 2.5-5.0 mm was activated by chemical activation technique using 60% H_3P0_4 as activating agent at impregnation ratio of 1 : 1. Sample was soaked overnight with the phosphoric acid for 24 hours and then dried at 110°C for 1 hour to remove moisture.

The impregnated sample was then carbonized using multiple furnace models at 700°C for 2 hours. After being cooled, the carbonized sample was washed several times with de-ionized water until the pH became neutral and finally washed with distilled water to remove residual chemicals. The washed sample was dried in an LTE oven at 110°C for 24 hours, crushed with glass rod and then stored for use. The chemical properties of the prepared adsorbent was carried out and shown in Table 2.

Batch adsorption studies

Adsorption experiments were carried out in six 250 cm^3 Erlenmeyer flasks where 20 mL of effluent sample was mixed with the appropriate amount of activated carbon in the range 20-40 g/L. In each, the flask was agitated at a temperature of 303 K using a magnetic stirrer at moderate speed for a period of time ranging from 10-60 mins respectively. The sample was then filtered with glass filters and Whatman No. 42 filter papers to remove activated carbon residue and the liquid filtrate was analyzed with respect to suspended solid content using a U-V visible spectrophotometer.

Analytical method

Adsorbed effluent samples were taken at different specified intervals (10-60 mins), filtered and then analyzed using a UV-vis spectrophotometer monitored at a wavelength of 291 nm but was obtained by serial dilution of the effluent.

The percentage removal of particles was evaluated by the following expressions:

$$\%\ \text{Removal} = \frac{C_0 - C_t}{C_0} \times 100 \qquad \ldots(1)$$

where C_o = original particle concentration (mg/L) and C_t is the concentration at time t (mg/L).

The amount of total suspended solids (TSS) adsorbed at time t was computed using the following equation[6].

$$q_t = \frac{(C_0 - C_t)V}{m}, \qquad \ldots(2)$$

where C_o and C_t are the concentrations of TSS in mg/L initially and at a given time t, respectively, V is the volume of the effluent in L and m is the mass of activated carbon in gramme. These therefore make the unit of q_t mg/g.

Analysis of variance (ANOVA)

In a situation where there are K groups (where K>2), the ANOVA technique becomes appropriate to make for efficiency[3]. ANOVA, also maintains the type one error rate at the pre-established alpha level[3]. Particularly, ANOVA is a procedure for partitioning the total source of variation in a set of data from a designed experiment, enabling the researcher to isolate and quantify the variances associated with each source of variation[7].

ANOVA test compares two variance estimations: the unsystematic variation or error in the data and variance due to the experiment[2].

In this paper, the variances due to the experiment are time, adsorbent dosage and interaction between time and adsorbent dosage.

The hypotheses were tested by using levels of significance (α) assumed as 0.05 and 0.01. If F_{cal} is greater than the F_{crit}, then, the result (variation due to time and adsorbent dosage has significant difference (null hypothesis is rejected). Otherwise, it can be concluded that there is no significant difference in the variations[2,4].

Two-way factorial analyses without replication

Factorial analyses are useful in research because the effects of more than one factor can be studied in a single experiment[4]. Some advantages of factorial analyses are[4]:

- Estimations of main effects, interactions and response surfaces are possible;
- They increase the scope of inference of the experiment.

F-LSD guards against type 1 error by preventing the researcher from comparing the treatments for differences when the F-test for treatments is not significant[4]. F-LSD values were calculated using equation 3[4]:

$$F - LSD_{\alpha} = t_{\alpha Error,df} \times S_{\bar{d}} \qquad \ldots(3)$$

where $t_{\alpha Error,df}$ is the $F - LSD_{\alpha}$ value at 0.05 confidence level and $S_{\bar{d}}$ is the standard deviation.

RESULTS AND DISCUSSIONS

Characterisation of COBAC

From Table 1, observed weight loss was due to the pre-treatment of COBAC for adsorption studies. Value of carbon yield, as shown in Table 1, is high and suggests the use of COBAC as an efficient adsorbent.

Table 1: Characterisation of COBAC

Parameter	Value
Yield (%)	69.27
Weight loss (%)	30.73
Bulk density (g/mL)	0.682
Ash content (%)	34.15
Fixed carbon (%)	31.96
Volatile (%)	29.04
Moisture content (%)	4.850

Adsorption efficiency

The values of adsorption efficiency from adsorption measurement for different COBAC dosage at pH of 12.2 and varying time are shown in Figure 1.

It can be seen that adsorption efficiency increases with COBAC dosage at increasing time. Figure 1 reveals that 40 g/L of COBAC gave the best adsorption performance variation such that after one hour of adsorption, COBAC performance got to about 96%.

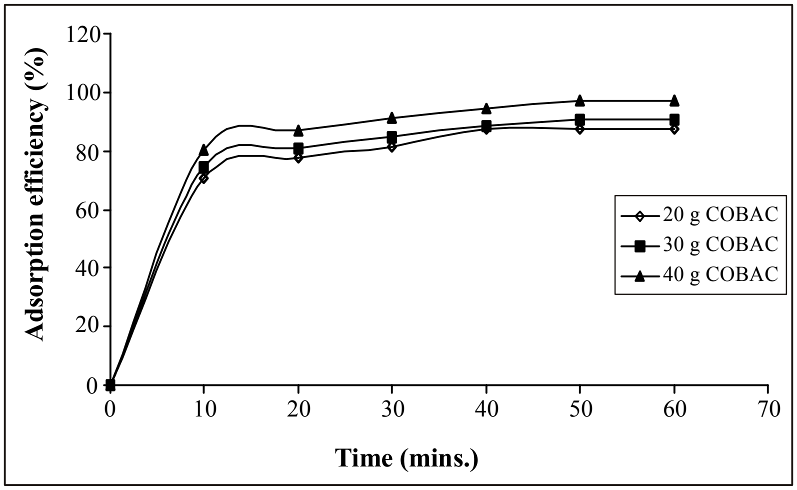

Fig. 1: Variation of COBAC adsorption efficiency with time at effluent pH of 12.2

Statistical approach to determining COBAC performance

From adsorption data, calculations for factorial analyses with respect to (adsorbent) dosage and time were done by means of "machine formulars". The analyses focused on how adsorption (dependent variable) can be influenced by independent variables (adsorbent dosage and time). The adsorbent dosage varied between 20 g/L and 40 g/L and the time range investigated varied between 10mins and 60 mins.

By means of "machine formulars", the correction for the mean (CFM), sum of squares total (SS_T), various sums of squares-treatment (SS_{treat}), error (SS_{error}), time (SS_{time}), dosage (SS_{dosage}) and time-dosage ($SS_{time\text{-}dosage}$), and various degrees of freedom-total (df), treatment (df_{treat}), time (df_{time}), dosage (df_{dosage}),time-dosage ($df_{time\text{-}dosage}$) and error (df_{error}) were determined as described in standard texts[4,7].

$$\text{Coefficient of variability (CV)} = \frac{S.D}{\overline{\overline{X}}} x100 \qquad \ldots(4)$$

was determined where S.D is the standard deviation and X is the grand mean (4) or mean of means. We obtained a coefficient of variability value of 3.995%. Since CV gives the degree of precision with which the factors are compared[7], then, our obtained CV value reflects excellent estimate of COBAC adsorption efficiency due to time and dosage.

To prepare tables to show the compared effects of time variation at various adsorbent dosages, equation (3) was used to obtain 5.9589 and 7.2201 which are the F-$LSD_{0.05}$ values (in adsorption efficiency units) for one-tail and two-tail tests, respectively.

Technique for comparing effects of time variation at various COBAC dosages were done as described/explained elsewhere[4] and tabulated as shown below.

Table 2: Comparing effects of time variation at 0.4 g/L COBAC dosage

Means	70.794	77.663	81.531	87.544	87.544	87.544
87.544	16.750	9.881	6.013	-	-	-
87.544	16.750	9.881	6.013	-	-	-
87.544	16.750	9.881	6.013	-	-	-
81.531	10.737	3.868	-	-	-	-
77.663	6.869	-	-	-	-	-
70.794	-	-	-	-	-	-

Table 3: Comparing effects of time variation at 0.6 g/L COBAC dosage

Means	74.225	80.669	84.538	88.400	90.550	90.550
90.550	16.325	9.881	6.012	6.150	-	-
90.550	16.325	9.881	6.012	6.150	-	-
88.400	14.175	7.731	3.862	-	-	-
84.538	10.313	3.869	-	-	-	-
80.669	6.444	-	-	-	-	-
74.225	-	-	-	-	-	-

Table 4: Comparing effects of time variation at 0.8 g/L CABAC dosage

Means	80.244	87.113	90.981	94.419	96.994	96.994
96.994	16.750	9.881	6.013	2.000	-	-
96.994	16.750	9.881	6.013	2.000	-	-
94.419	14.175	7.306	3.438	-	-	-
90.981	10.737	3.868	-	-	-	-
87.113	6.869	-	-	-	-	-
80.244	-	-	-	-	-	-

Adsorption efficiency was not significantly different for COBAC dosage of 20 g/L at 20 minutes; 30 g/L at 20 and 30 minutes; and 40 g/L at 20-40 minutes. These observations can be concluded to mean that increasing COBAC dosage from 20-40 g/L had a non significant difference in adsorption efficiency after 10 minutes.

Table 5: Final analysis of variance of COBAC adsorption efficiency

Source of variation	**df**	**SS**	**MS**		**F_{Cal}**	**F_{Tab}**
			5%	**10%**		
Time	5	655.669	131.134	389.122*	3.330	5.640
Dosage	2	256.973	128.486	381.264*	4.100	7.560
Error	10	3.374	0.337			
Total	17					

*Means highly significant, df means degree of freedom, SS means sum of squares, MS means mean of squares, F_{Cal} and F_{Tab} respectively mean calculated and tabulated F-ratio values

From Table 5, the following can be concluded: increasing COBAC dosage between 20-40 g/L; and increasing adsorption time from 10-60 minutes, have highly significant differences on COBAC adsorption performance.

Main effects of time and COBAC dosage, and the dosage-time and time-dosage interactions studied, are shown in Figures 2-5 below.

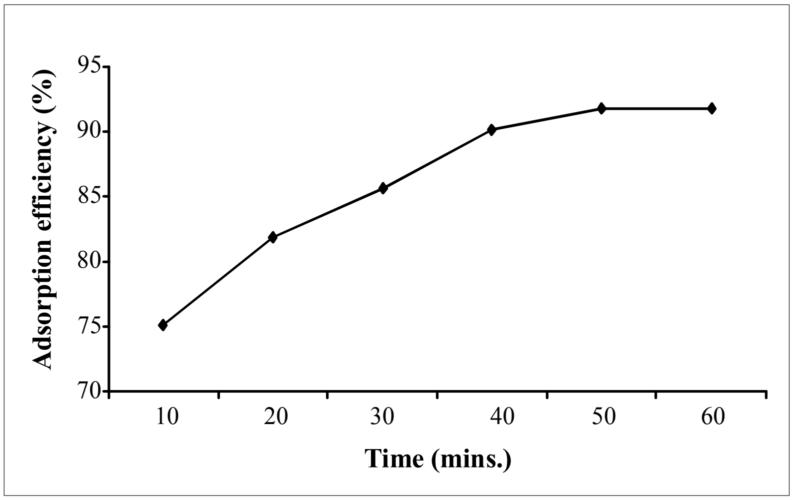

Fig. 2: Main effect (average effect) of time

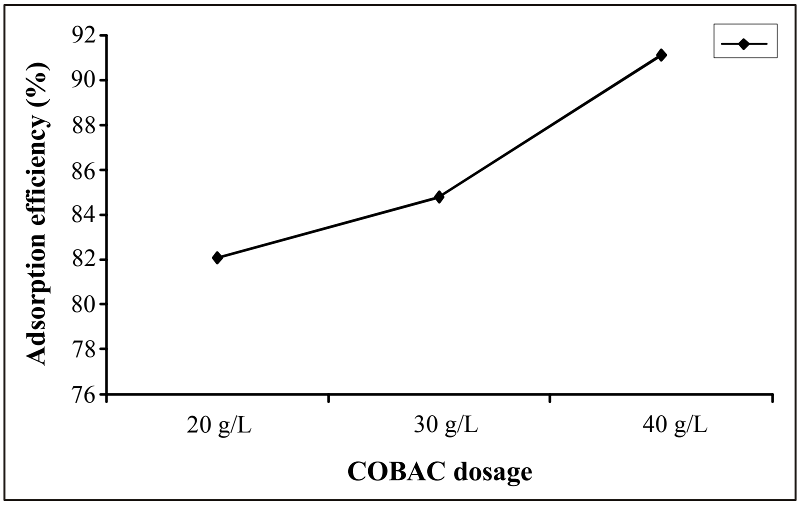

Fig. 3: Main effect (average effect) of dosage

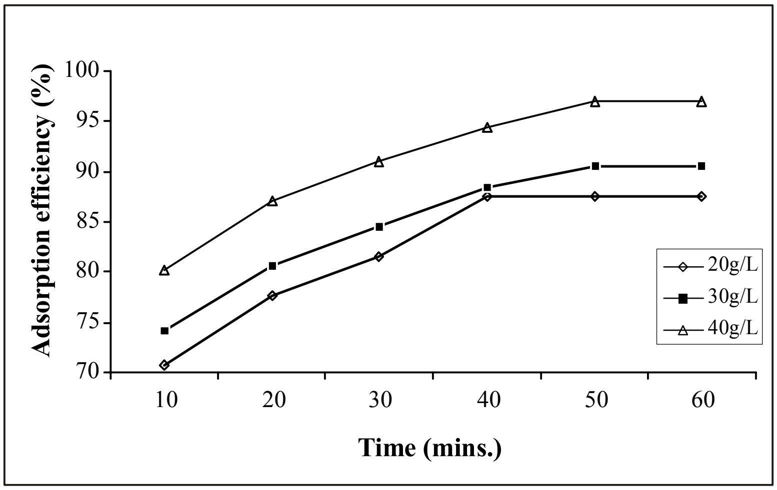

Fig. 4: Dosage/Time interactions (DT)

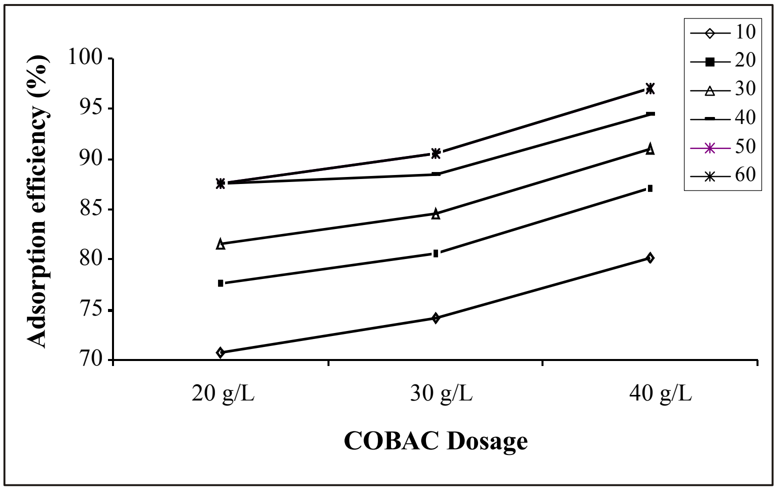

Fig. 5: Time/Dosage interactions (TD)

Results of plots shown in figures 2-5 above can be summarized below:

- Figure 2 reveals that increase in time increased adsorption efficiency of COBAC;
- Figure 3 reveals that increase in COBAC dosage increase adsorption efficiency;
- Figure 4 shows that interactions exist for all dosage at 50 mins and 60 mins. It implies that at higher time than 50 mins and whatever dosage, adsorption efficiency of COBAC was the same. Therefore, 50mins is the optimum time for COBAC adsorption performance.

- Figure 5 shows highest performance at all times 40 g/L (0.8 g/20 mL) dosage. Hence, 40 g/L COBAC dosage is the optimum dosage for maximum performance;
- Figures 4 and 5 reveal that COBAC dosage and time had interactions such that increments in time and COBAC dosage, increased adsorption performance of COBAC.

Adsorption dynamics

Adsorption dynamics describes the rate at which TSS in the industrial effluent was removed. In this study, two kinetic models were used to ensure adequate kinetic analyses of adsorption of TSS from the industrial effluent onto COBAC. These two kinetic models are: pseudo first order model (type I and II)) and pseudo second order model (type I, II, and III).

The Pseudo first order equation

Generally, the pseudo first-order equation can be expressed thus[8]

$$\frac{dq}{dt}=K_1(q_e-q_t) \qquad \ldots(5)$$

where q_e and q_t are the adsorption capacities at equilibrium and at time t, respectively, K_1 is the rate constant of pseudo first-order adsorption. Equation (5) is a differential equation, and solving it, by applying conditions gives

$$\int_o^{q_t}\frac{dq_t}{q_e-q_t}=K_1\int_0^t dt \qquad \ldots(6)$$

to give

$$\ln(q_o-q_t)=\log q_e-K_1t \qquad \ldots(7)$$

Therefore, $\ln(q_o-q_t)$ versus t plot was made and K_1 obtained from the slope of the plot. We designated type I to obtained kinetic parameter from equation (7).

Rearranging equation (5), we also obtained

$$k_1=\frac{dq_t}{dt}\left(\frac{1}{q_e-q_t}\right) \qquad \ldots(8)$$

where $\frac{dq_t}{dt}$ is the rate of pseudo first-order adsorption. Various k_1 values were obtained; these k_1, values were added/summed and an average value gotten.

The determined k_1 values from slope of equation (7) plot and that gotten from the average value from equation (8), were needed to calculate predicted adsorption capacity at time t from equation (9) below -

$$q_t = q_e\,(1-e^{-kt}) \qquad \ldots(9)$$

Type II was assigned to obtained kinetic parameter from equation (8).

The Pseudo Second –Order Equation

The pseudo second-order equation can be expressed as[8] -

$$\frac{dq_t}{dt} = k_2 (q_e - q_t)^2 \qquad \ldots(10)$$

where k_2 is the rate constant of pseudo second-order adsorption. Equation (10) can be solved when rearranged and boundary conditions applied, to give

$$\int_0^{q_t} \frac{dq_t}{(q_e - q_t)^2} = k_2 \int_0^t dt \qquad \ldots(11)$$

Solution of equation (11), gives

$$\frac{1}{q_e - q_t} = \frac{1}{q_e} + k_2 t \qquad \ldots(12)$$

$(q_e - q_t)^{-1}$ versus time plot gave k_2 as slope. However, equation (12) can be rearranged to give

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \qquad \ldots(13)$$

$\frac{t}{q_t}$ versus time plot will enable, from the intercept the determination of k_2.

Equation (10) can also be rearranged to give 'animekus' expression

$$k_2 = \frac{dq_t}{dt}\left(\frac{1}{q_e - q_t}\right)^2 \qquad \ldots(14)$$

where $\frac{dq_t}{dt}$ is the rate of pseudo second-order adsorption. Various k_2 values were obtained, summed up, and an average value obtained. From equations (12), (13) and (14) respectively, obtained kinetic parameters were assigned type I, II and III.

Predicted adsorption capacity at time t can be obtained from equation (15) when obtained k_2 values from equations (12) and (13) and average k_2 value from equation (14) are substituted.

$$q_t = \frac{q_e^2 k_2 t}{1 + q_e k_2 t} \qquad \ldots(15)$$

The necessary mass transfer kinetic plots enabled the determinations of various kinetic parameters shown in figure (6).

A comparison of calculated and measured adsorption capacity at time t (q_t) is shown in figure (6). As can be seen in figure (6), pseudo fist-order (types I and II), pseudo second-order (types I, II and III) kinetic models, and experimentally obtained adsorption capacity values at time t for 40 mg/L COBAC at effluent pH of 12.2 is shown in figure (6).

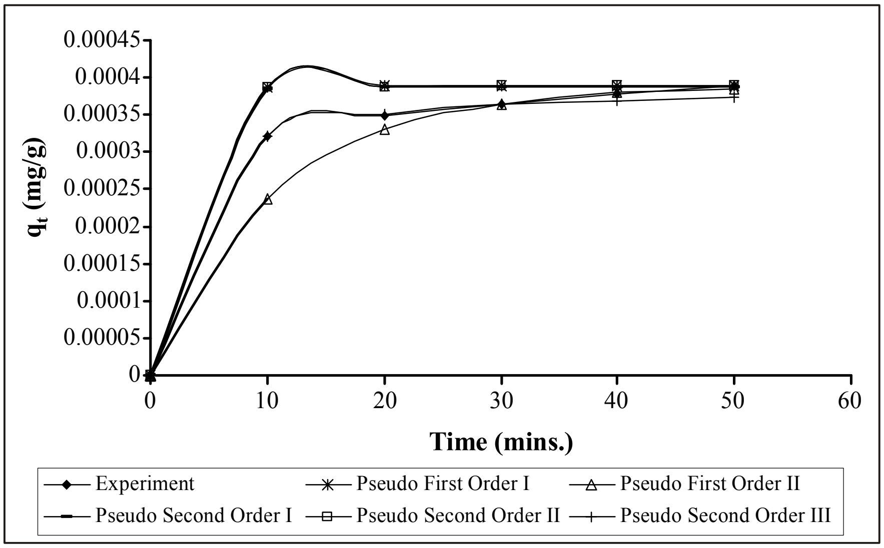

Fig. 6: Comparison between the measured and modeled time profiles for adsorption of an industrial effluent on COBAC at effluent pH of 12.2

It is therefore vital that the best fit is obtained. To be able to do so, the chi-square statistics was used to determine which kinetic model performed best in describing the adsorption mechanism involved. The following formular was used to obtain the chi-square values[3].

$$\text{Chi-square } \left(x^2\right) = \sum \frac{\left(q_{t\,\exp} - q_{t\,cal}\right)^2}{q_{t\,cal}} \quad \ldots(16)$$

Chi-square values obtained were 0.01712 and 0.6413 for pseudo first-order kinetic model (type I and II respectively) and 0.07901, 0.08201 and 0.00094 for pseudo second-order kinetic model (type I, II and III respectively).

The obtained chi-square values show that the pseudo second-order kinetic model (type III) gave the best results and is supported by a comparison plot shown in figure (6). This suggests that the studied adsorption process involved chemisorptions[9].

Adsorption equilibrium and thermodynamic studies

Three adsorption isotherms were used to ensure adequate adsorption analyses of TSS from an industrial effluent unto COBAC. It is vital to establish the most appropriate adsorption isotherm or equilibrium curve so that one can optimize the design of an adsorption system to remove TSS from industrial effluents. The Langmuir, Temkin, and Fruendlich isotherms were used to fit experimental adsorption data in the present study.

Adsorption studies were carried out with a fixed initial TSS of effluent and varying COBAC dosage, and the obtained data fitted to Langmuir adsorption isotherm which can be represented thus:

$$q_e = \frac{q_o k_L C_e}{1 + k_L C_e} \quad \ldots(17)$$

where q_e is the amount of TSS adsorbed at equilibrium, C_e is the equilibrium concentration of TSS, q_o and k_L are Langmuir constants related to the adsorption capacity and energy of adsorption respectively. Linearising equation (17), the following expressions can be obtained

$$C_e/q_e = 1/k_L q_o + C_e/q_o \quad \ldots(18)$$

commonly known as Langmuir-I and

$$q_e = q_o - {q_e}/{k_L C_e} \qquad \ldots(19)$$

commonly known as Langmuir-III. Obtained Langmuir constants are presented in Table 6.

Table 6: Langmuir, Temkin, Freundlich and Dubinin-Radushkevich isotherm constants for COBAC adsorption

Langmuir-I	Langmuir-III	Temkin	Freundlich
K_L 0.123	K_L 15.000	B -50,000	K_F 4.059 × 10^{-4}
a_L -0.274	a_L 50,000	A 2.061 × 10^{-9}	n -19.417
q_o -0.449	q_o 0.0003		
R_L 1.0044	R_L 0.0012		

Commonly, a dimensionless separation factor given by equation (20) is used to describe the adsorption characteristics of effluent/adsorbent system.

$$R_L = \frac{1}{1 + K_L C_e} \qquad \ldots(20).$$

Obtained R_L values are shown in table 8. R_L value of 0.0012 reveals favourable adsorption process.

The adsorption energy values (ΔG) were determined by substituting Langmuir parameter (K_L) into equation (21) using

$$\Delta G = -RTLnK_L \qquad \ldots(21)$$

Obtained energy of adsorption values are presented in table 9. Negative values of adsorption energy indicate spontaneous and efficient adsorption process. For different COBAC dosage, the ratio of q_e to C_e was done to give K_d. Also, energy of adsorption (ΔG^*) is related to K_d thus

$$\Delta G^* = -RTLnK_d \qquad \ldots(22)$$

Using equation (22), energy of adsorption values were obtained from equilibrium data. Values gotten, presented in table 9, are found to decrease when COBAC dosage increases and suggest better adsorption at higher COBAC dosage. This can be explained to be due to increased surface area which increased adsorption sites, hence, gave better adsorption by COBAC.

Adsorption data were analysed according to the linear form of the Freundlich isotherm represented by equation (23)[10]:

$$Lnq_e = \ln K_f + \frac{1}{n}\ln C_e \quad \ldots(23),$$

where K_f and n are Freundlich parameters. The Freundlich isotherm gave the poorest fit of our adsorption data.

The adsorption data was also fitted to Temkin adsorption isotherm represented by an expression below[10].

$$q_e = \frac{1}{f}(\ln A + \ln C_e) \quad \ldots(24)$$

where A and B are Temkin adsorption parameters. Average percentage error (APE) and chi-square (χ^2) statistics predicted the Temkin isotherm to give better fit than the Freundlich isotherm but the Langmuir isotherm gave the best fit. As figure 7 reveals, the linear form of Langmuir isotherm, Langmuir-III, gave the best description for TSS adsorption on COBAC.

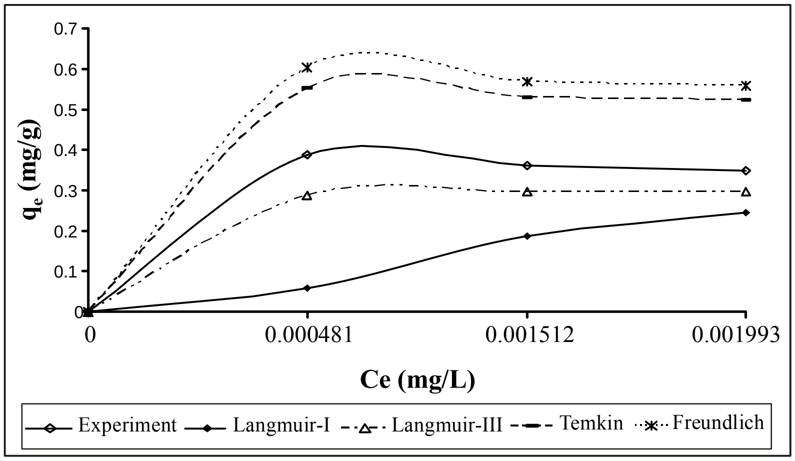

Fig. 7: Equilibrium isotherms of TSS on COBAC. Conditions: 40 g/L dose, 30°C temperature and pH 12

Figure 8 displays how pH variations of effluent influenced COBAC adsorption performance. It can be deduced that pH of 6 is the best/optimum pH at which COBAC adsorption performance is highest.

From figure 9, we observed that before 30 minutes, COBAC performed best at 303

Kelvin. However, after 40 minutes, it’s performance was found to have slight differences at studied temperatures. It is therefore advisable that for purification of industrial effluents of TSS, COBAC usage in temperate and tropic regions is handy, hence, recommended. This is because these regions of the earth have temperatures commonly not 35°C (308 Kelvin).

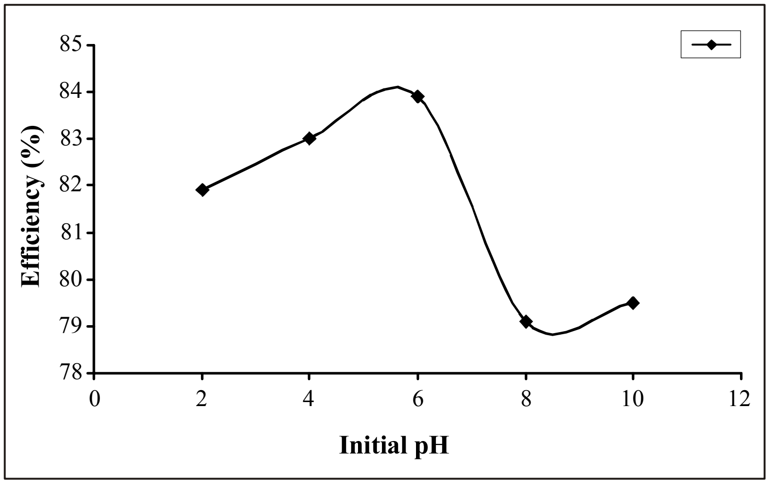

Fig. 8: Effect of pH on adsorption of TSS by COBAC. Conditions: 0.0160 g/L concentration, 50 minutes contact times, 40g/L dose, and 25ºC temperature

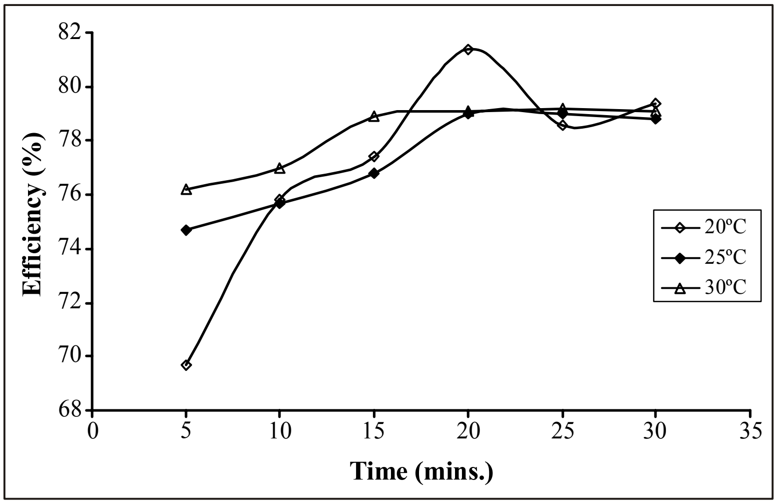

Fig. 9: Effect of temperature on adsorption of TSS by COBAC. Conditions : 0.0160 g/L concentration, 40 g/L dose and 50 minutes contact time

Table 7: Thermodynamic parameters for TSS adsorption onto COBAC at 303Kelvin

ΔH (J/mol)	ΔS (J/mol)	ΔH_{iso} (KJ/mol)	ΔG (KJ/mol)	ΔG* (KJ/mol)		
				^1K_d	^2K_d	^3K_d
-1.176	-21.167	-17.347	-27.257	4.376	3.606	0.540

$\Delta G^* = -RTLnK_d$ where $K_d = {}^{q_e}\!/\!_{C_e}$ and respectively $^1K_d, ^2K_d and ^3K_d$ are K_d values obtained for 20, 30 and 40 g/L COBAC dosage; $\Delta G = -RTLnK_L$ and ΔH_{iso} is isosteric heat of adsorption.

Designing batch adsorption from equilibrium data

From the best fit isotherm, a single stage adsorber can be designed for different solution volumes as shown in figure 10 below and as described elsewhere[11].

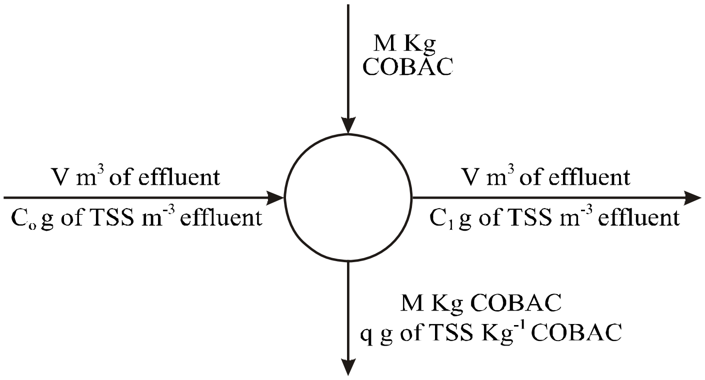

Fig. 10: Single stage adsorber flowchart

Let the effluent contain V m^3 solution and the TSS concentration be reduced from C_o to C_1 g TSS per m^3 solution after been through the adsorber. Also, let the amount of COBAC be M kg and TSS loading onto COBAC become q g TSS per kg COBAC. The mass balance equation for the sorption system can be written as

$$V(C_0 - C_1) = Mq \qquad \ldots(23).$$

At equilibrium, C_1 becomes C_e and q becomes q_e. Considering that adsorption of TSS on COBAC was best described by the Langmuir-III isotherm, rearranging equation (23) and substituting into equation (24) the expression for q_e represented by equation (17).

$$M = \frac{V(C_0 - C_1)}{q} = \frac{V(C_0 - C_e)}{q_e} = \frac{V(C_0 - C_e)}{\frac{K_L C_e}{1 + a_L C_e}} \qquad \ldots(24)$$

Figure 11 shows plots obtained from equation (24) for TSS adsorption onto COBAC. Figure 12 shows the required amount of COBAC to remove TSS by 90% at various volumes of effluents containing different TSS concentrations.

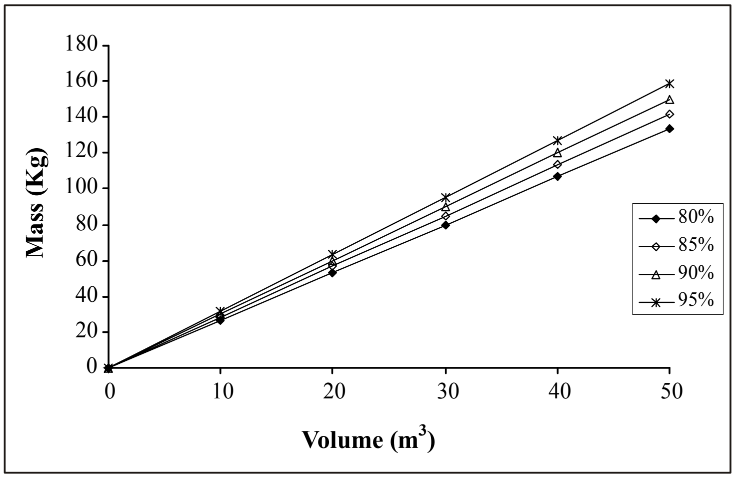

Fig. 11: COBAC mass versus volume of effluent treated for various % of TSS removal at 1 g/L initial TSS concentration

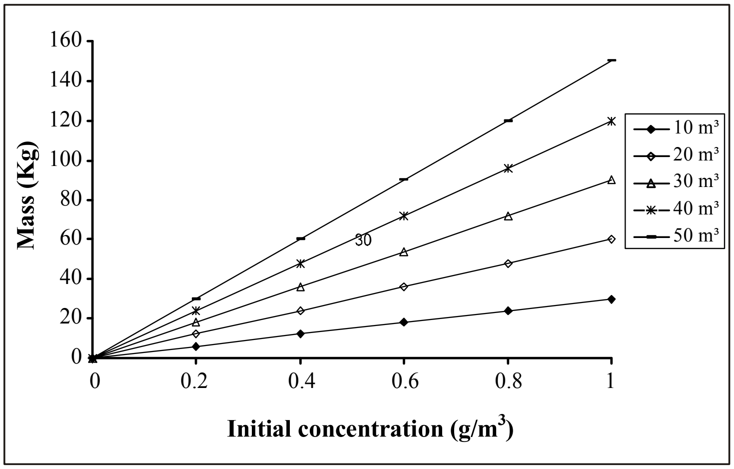

Fig. 12: COBAC mass versus initial TSS concentration for 90% TSS removal at various volume of effluent treated

CONCLUSION

Two-way factorial analyses were conducted for the adsorption of suspended particles from an industrial effluent onto coal activated carbon. The effects of time, dosage and time/dosage interactions on COBAC adsorption efficiency were studied using ANOVA and Fisher's Least Significant Difference (FLSD). These suggest that 40 g/L COBAC dosage at effluent pH of 12.2 is the best adsorption dosage obtained at 50 minutes within the studied conditions. Increasing time, COBAC dosage and time/dosage interactions which positively affected adsorption performance of COBAC.

The kinetics of adsorption of suspended particles onto COBAC was studied using pseudo first-order and pseudo second-order kinetic models. The animekus expression for the pseudo second-order kinetic model (type III), gave the best predicted adsorption capacity values, thus, favouring chemisorptions mechanism as the rate determining step.

From temperature variation studies, changes in enthalpy (ΔH), entropy (ΔS) and energy of adsorption (ΔG) were evaluated. For various COBAC dosages, ΔG values obtained are positive, however, these values decrease with increase in COBAC dosage. It reveals that TSS adsorption onto COBAC increase when COBAC dosage increase, hence, TSS removal was better at higher COBAC dosage. The negative value of ΔH suggests that TSS adsorption on COBAC was exothermic. The negative ΔS value reveal efficient adsorption and indicates that adsorption process changed from less ordered to more ordered system.

Equilibrium studies for the TSS adsorption onto COBAC from an industrial effluent were done using Langmuir, Temkin, and Freundlich isotherms. The Langmuir-III linear isotherm gave the closest adsorption capacity values to experimental values.

On the assumption that the batch adsorption was a single-staged equilibrium process, the operation can be described mathematically. The mathematical description uses the Langmuir-III linear isotherm constants to predict the residual TSS concentration or amount of COBAC required for the separation process.

The results of this work reveal that COBAC has very good potential for the removal of suspended particles from industrial effluents at alkaline medium. COBAC therefore can be concluded to be a low cost, naturally and easily available adsorbent for the removal of suspended particles.

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