

# Multi Component Adsorption of Toluene, Ethyl Benzene and Meta- Xylene by Batch Adsorption Technique Using Natural and Acid Treated - Modified Sodium Bentonite

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**Abstract:** Sodium bentonite was treated with phosphoric acid and was further modified using hexadecyltrimethylammonium bromide (HDTAB). The acid treated - modified sodium bentonite and natural sodium bentonite were both used for the multi component adsorption of toluene, ethyl benzene and meta-xylene from their aqueous solution. The FT-IR analysis result revealed the presence of hexadecyltrimethylammonium bromide (HDTAB) in the modified sodium bentonite. Foster swelling test result showed that only the acid treated - modified sodium bentonite swelled in the petrochemical solvents and the order of the swelling factor is given as; meta- xylene > ethyl benzene > toluene. The result of the batch adsorption technique showed that the percentage removal of toluene and ethyl benzene using acid treated - modified sodium bentonite increased from 65.64% to 91.55% and from 74.33% to 95.30% as contact time increased from 30 minutes to 150 minutes, while the percentage removal of meta -xylene increased from 81.53% to 99.56%. The multi component adsorption of meta- xylene, ethyl benzene and toluene is best described using pseudo- second- order kinetics and Freundlich isotherm model because the data obtained are best fitted with pseudo- second- order kinetics and Freundlich isotherm.

**Keywords:** Bentonites, HDTAB-bentonites, toluene, ethyl benzene, meta-xylene, adsorption.

## 1 INTRODUCTION

Human activities such as industrialization, rural and urban development has led to continuous pollution and contamination of the environment, precisely land, air and water pollutions. These pollutions occur as a result of the introduction and the ingress of untreated waste water containing pollutants spawned by petrochemical industries and oil refineries into the water bodies. Some of these pollutants include some organic and petrochemical compounds such as benzene, toluene, ethyl benzene and xylene (BTEX), which are quite detrimental and very harmful to human health even at their minimal concentration (Eman, 2013; Jorge *et al.*, 2012). Toluene, ethyl benzene and xylene are water insoluble aromatic compounds which are clear, transparent and colourless liquid hydrocarbon solvents. They are flammable liquid and possess an aromatic smells. These aromatic compounds, when inhaled or comes in contact with the skin, can cause several diseases and ailment to humans such as depression, euphoria, liver and kidney failure, redness of the skin and eye, vomiting, dizziness and can equally lead to death of humans (Lemarroy *et al.*, 2015; Kandyala *et al.*, 2010; Shifko, 2015). These effects and diseases must be minimized by the utilization of a suitable adsorbent such as bentonite for treatment of waste water from petrochemical industries and refineries prior to their discharge to the environment and water bodies. Bentonite is a clay mineral which is naturally found in most countries of the world, which is formed as a result of chemical alteration of the volcanic ash and can also be formed during divitrification process (Arthur and Robert, 2010; Clarence and Earl, 1926). Bentonite is usually found alongside with some mineral such as mica, feldspar, cristobalite, attapulgite, quartz, calcite, kaoline and some others, although they

occur in a small quantity. Bentonite clay is a useful mineral that can be utilized in several discipline such as agriculture, petroleum industries, medicine, pharmaceutical industries, civil engineering, animal feed stuff, animal pens, paper industries, paints and varnish industries, cosmetic industries and water treatment industries. In water treatment process, modified bentonite has been proven to be an efficient and an effective adsorbent and also a purifying agent for the removal of organic and petrochemical contaminants from wastewater (Hosterman and Patterson, 1992; Obi and Apemiye, 2017; Thakre *et al.*, 2010).

The objective of this study is to determine the suitability of acid treated HDTAB - modified sodium bentonite in the removal of meta-xylene, ethyl benzene and toluene from aqueous solution. The effect of variation in adsorbent weight, contact time and initial concentration were also determined.

## **2 MATERIALS AND METHODS**

### **2.1 MATERIALS**

The sodium bentonite (Na – bentonite) exploited in this research was collected from Mansid Nigeria Limited, Port Harcourt Rivers State, Nigeria. Phosphoric acid (85% purity), Hexadecyltrimethylammonium bromide, meta- xylene, ethyl benzene and toluene were purchased from Sigma - Aldrich Company, Switzerland at > 98% purity, and were utilized for the research without additional purification.

### **2.2 ADSORBENT ACTIVATION AND MODIFICATION**

The adsorbent activation and modification were carried out following the method adopted by Bedin *et al.*, 2013. Ten (10) gram of sodium bentonite was weighed and steeped in 200 ml of distilled water for a period of 24 hours. The bentonite - water mixture was stirred for 30 minutes prior to the addition of 200 ml of 1M of phosphoric acid and was subsequently stirred, heated and refluxed at a temperature of 75 °C for two hours. Thereafter the mixture was filtered and a measurement of 200 ml of 0.05 M of HDTAB (Hexadecyltrimethylammonium bromide) solution was added to the acid treated bentonite which was stirred and refluxed at a temperature of 75 °C for another two hours. Finally the mixture was filtered and oven dried at 105 °C for a duration of three hours. The dried HDTAB - modified bentonite was properly stored and preserved in sample containers for characterization and batch adsorption. The whole process was reiterated for different concentration of HDTAB.

### **2.3 ADSORBENT CHARACTERIZATION**

#### **2.3.1 FT- IR ANALYSIS**

This analysis was carried out at a range of 400 – 4000  $\text{cm}^{-1}$  with Fourier transformed infrared spectrometer (model number IR AFFINITY -1). The samples were analyzed using KBr (potassium bromide) technique and method. A measurement of 1.5 mg of the natural and acid – treated - modified sodium bentonite were successively homogenized with 150 mg of pure KBr and the mixture was adequately and duly screwed and compressed to form a disc which was then scanned in the machine.

#### **2.3.2 FOSTER SWELLING TEST**

This Foster swelling test was carried out in view of the method adopted by Paiva and Morales, 2012; Burgentzle *et al.*, 2004. The unmodified and the acid treated - modified sodium bentonite were both used for this test. A measured amount of 0.5 gram of the adsorbent was added to a 50 ml glass tube and the volume occupied by the bentonite sample was recorded. Fifty (50) ml of toluene was added to the glass tube containing the bentonite and the mixture was uninterruptedly allowed to stand for a period of 24 hours. The new volume,

$V_B$  of the adsorbent was recorded after 24 hours and agitation was subsequently carried out. After shaking, the toluene – bentonite mixture was again uninterruptedly allowed to stand for 24 hours and the final volume,  $V_A$  was recorded. The test was repeated using other solvents (Meta - xylene, ethyl benene and water). The swelling factors ( $F_{SB}$  and  $F_{SA}$ ) are calculated using equations 1 and 2

$$F_{SB} = \frac{V_B - V_I}{V_I} \quad (1)$$

$$F_{SA} = \frac{V_A - V_I}{V_I} \quad (2)$$

$F_{SB}$  and  $F_{SA}$  are the swelling factors before and after agitation respectively,  $V_B$  and  $V_A$  are the volume of the adsorbent before and after agitation respectively, While  $V_I$  is the initial volume of the adsorbent in the glass tube prior to solvent addition.

## 2.4 BATCH ADSORPTION EXPERIMENT

A measurement of 0.5 gram of the adsorbent was successively added to 120 ml capacity plastic container and 20ml solution (100 mg/L) of the adsorbates mixture (a mixture of toluene, ethyl benzene and meta-xylene mixture) was subsequently added. The container was firmly covered to avoid solvent loss which may emanate from evaporation and the mixture was subjected to 60 minutes shaking at 400 rpm using mechanical shaker (model number, J.P. SELECTA, 7000384) after which the supernatant solution was adequately decanted and was duly and properly analyzed with Uv- visible spectrophotometer (model number, GENESYS 10uv) at 315nm, 290nm and 325nm for toluene, ethyl benzene and meta – xylene respectively. The adsorption process was reiterated by varying contact time, adsorbate concentration and adsorbent weight. A blank analysis was carried out in order to ensure that no reaction occurred between the container and the adsorbates, and also to ascertain adsorbate loss through evaporation. The percentage removal (% R) and the adsorption capacity ( $q_e$ ) were calculated using equation 3 and 4

$$\text{Percentage removal, \% R} = \frac{C_0 - C_e}{C_0} \times 100 \quad (3)$$

$$\text{Adsorption capacity, } q_e = \frac{C_0 - C_e}{m} \times V \quad (4)$$

Where  $m$  is the adsorbent mass (g),  $V$  is the adsorbate volume (ml),  $C_0$  and  $C_e$  are the adsorbate initial and final concentration (mg/L) respectively.

## 3 RESULTS AND DISCUSSION

### 3.1 ADSORBENT CHARACTERIZATION

#### 3.1.1 FT – IR ANALYSIS

The FT- IR spectral results of the acid treated - HDTAB - modified and natural bentonite are shown in figure 1. The broad band appearing at  $3416 - 3622 \text{ cm}^{-1}$ , ascertained the existence of O-H vibration of water adsorbed silica surface (Sari *et al.*, 2007). An adsorption band appeared at  $1645 \text{ cm}^{-1}$  which denoted the presence of H-O-H bending vibration whereas the broad bands at  $1047 \text{ cm}^{-1}$  and  $1051 \text{ cm}^{-1}$  could be attributed to the stretch vibration of Si-O-Si groups. Two

prominent peaks were seen at  $2858\text{ cm}^{-1}$  and  $2996\text{ cm}^{-1}$  on the spectral result of the acid treated – modified bentonite which shows the presence of  $-\text{CH}_2$  and  $-\text{CH}_3$  stretching vibration respectively. A pronounced deformation peak of the H-O-H group appeared at  $1503 - 1625\text{ cm}^{-1}$  (Eren, 2008).

The existence of methylene group and methyl group, on the acid treated - modified sodium bentonite practically confirmed the presence of Hexadecyltrimethylammonium bromide in the modified sodium bentonite. The peak occurring at  $2907\text{ cm}^{-1}$  on both the HDTAB modified and unmodified shows the presence of P – OH bond which is as a result of the acid activation carried out on the bentonite clay mineral.

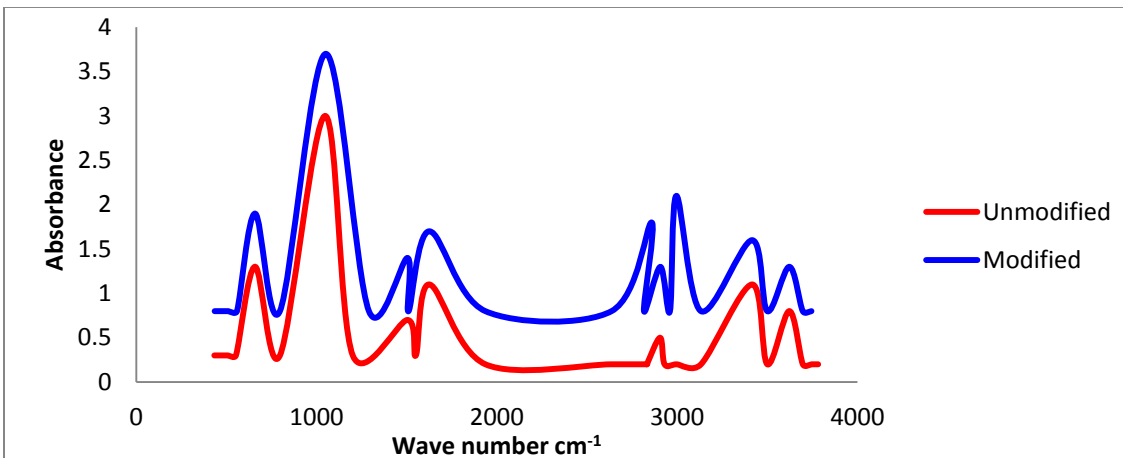


Figure 1. FT- IR spectral of unmodified (red) and HDTAB modified (blue) sodium bentonite.

### 3.1.2 FOSTER SWELLING TEST

From the results in figure 2 and 3, acid treated - modified sodium bentonite swelled higher than their original volume in petrochemical/ hydrocarbon solvents (toluene, ethyl benzene and meta - xylene) but didn't swell in water. The ability of the acid treated – modified sodium bentonite to swell in organic solvent apparently revealed a change in the hydrophilic to organophilic property of the bentonite. The unmodified sodium bentonite swelled in water but didn't swell in organic/hydrocarbon solvents. This emanated from the ability and the capacity of the internal and external surface of the bentonite clay to become hydrated when it comes in contact with water. Sodium is the exchangeable positive ion in sodium bentonite which facilitates the promotion of oriented water layers. When bentonite clay mineral is soaked in water, the hydrogen bonds in water cause water layers to be adsorbed within the structures of the bentonite clay mineral, hence causing the bentonite layers to separate further apart. This leads to swelling and expansion of the bentonite clay mineral. (Moore and Reynolds, 1997; Wersin, *et al.*, 2004). Unmodified sodium bentonite didn't swell in the hydrocarbon solvents because of its organo-phobic character which hinders its interaction with the hydrocarbon/organic solvents.

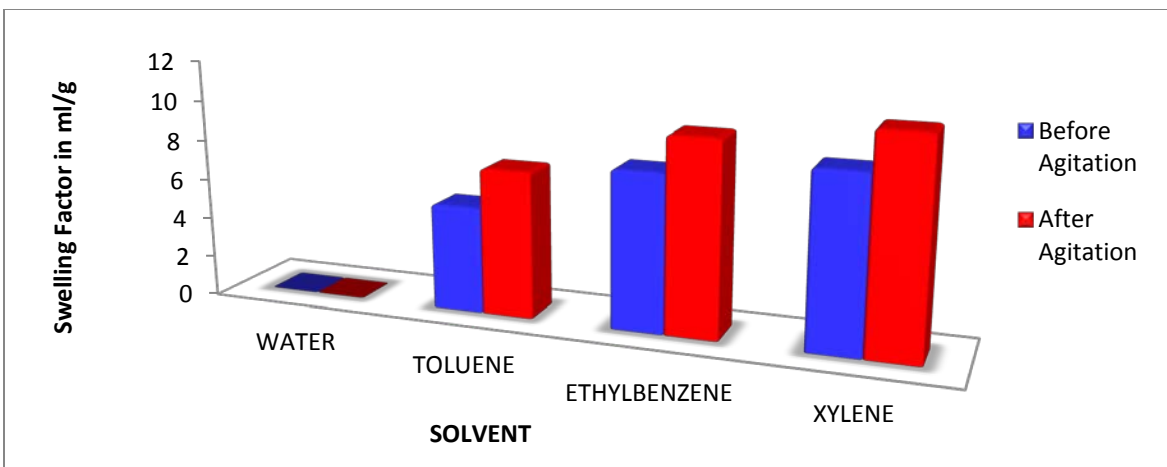


Figure 2. The swelling factor of acid treated - modified sodium bentonite in petrochemical solvent and water.

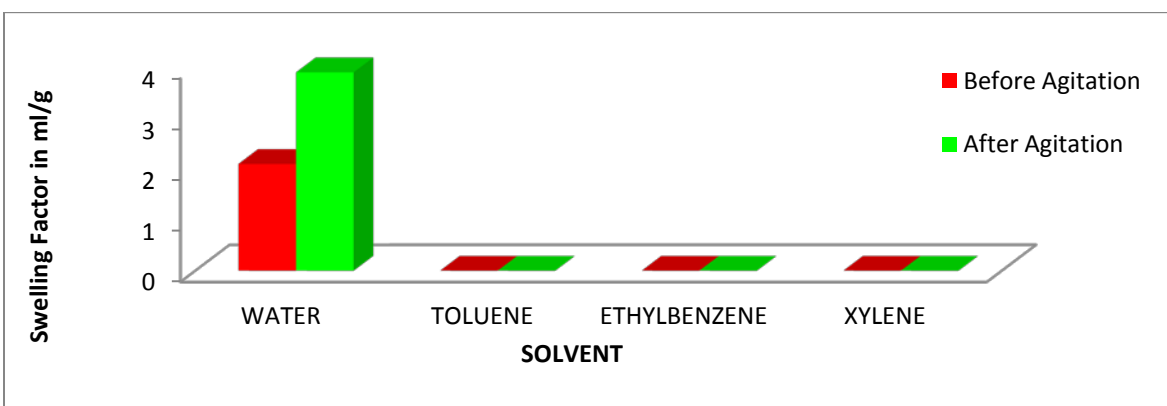


Figure 3. The swelling factor of unmodified sodium bentonite in petrochemical solvent and water.

### 3.2 BATCH ADSORPTION RESULT

#### 3.2.1 EFFECT OF VARYING CONTACT TIME

The effect of contact time on the adsorption capacity and the percentage removal of toluene, ethyl benzene and meta – xylene as shown in figure 4 apparently increased from 65.64% to 91.55%, 74.33% to 95.30% and from 81.53% to 99.56% respectively as the contact time increased from 30 minutes to 150 minutes. The percentage removal of meta- xylene is higher than that of ethyl benzene and toluene as shown in figure 4. The order of adsorption and removal is given as; meta – xylene > ethyl benzene > toluene. This is as a result of their molecular weight, meta – xylene is heavier than ethyl benzene and the later is heavier than toluene. The lighter, more soluble and the higher hydrophilic adsorbate will show a minimal inclination to be attracted to the modified adsorbent during the process of adsorption while the heavier and less soluble adsorbate will show a greater tendency to be removed from the aqueous solution. The result showed that the affinity of acid treated - modified sodium bentonite towards

toluene, ethyl benzene and meta - xylene increases with increasing time. This shows that contact time is a paramount factor to be considered in adsorption process. This result is in line with the result obtained by Obi and Apemiye, 2017.

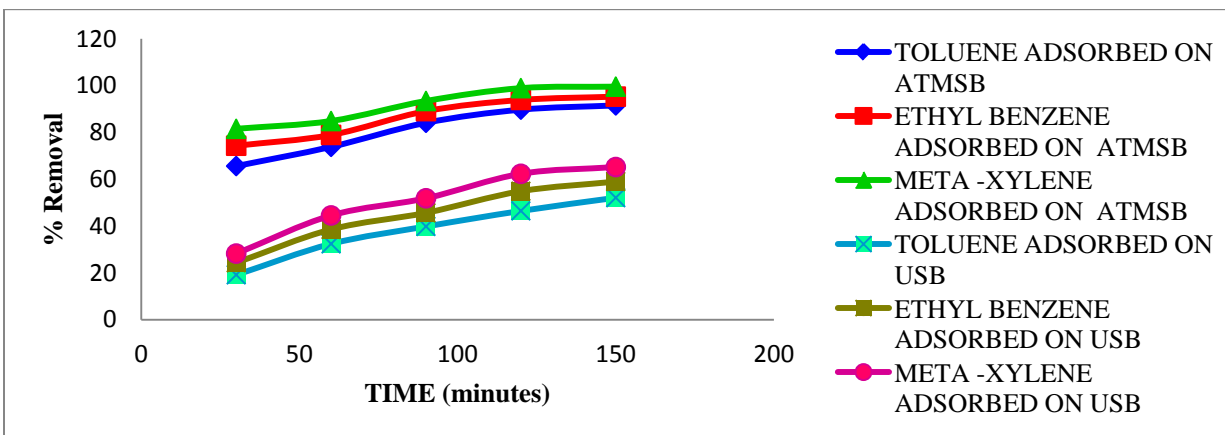


Figure 4. Effect of contact time on the % removal of meta – xylene, ethyl benzene and toluene using modified and unmodified sodium bentonite. ATMSB = Acid treated –modified sodium bentonite. USB = Unmodified sodium bentonite.

### 3.2.2 EFFECT OF VARYING ADSORBENT WEIGHT

Figure 5 shows the effect of adsorbent weight. The percentage removal of meta- xylene, ethyl benzene and toluene increased from 48.76% to 94.94%, from 42.56% to 89.33% and from 36.97% to 83.52% respectively as the adsorbent weight increased from 0.2g to 1.2g. This is as a result of more adsorption site. Further increase of the adsorbent weight to 1.6g demonstrated no much difference because the adsorbent adsorption site has attained equilibrium adsorption capacity. This result is in line with the result obtained by Aamir *et al.*, 2017.

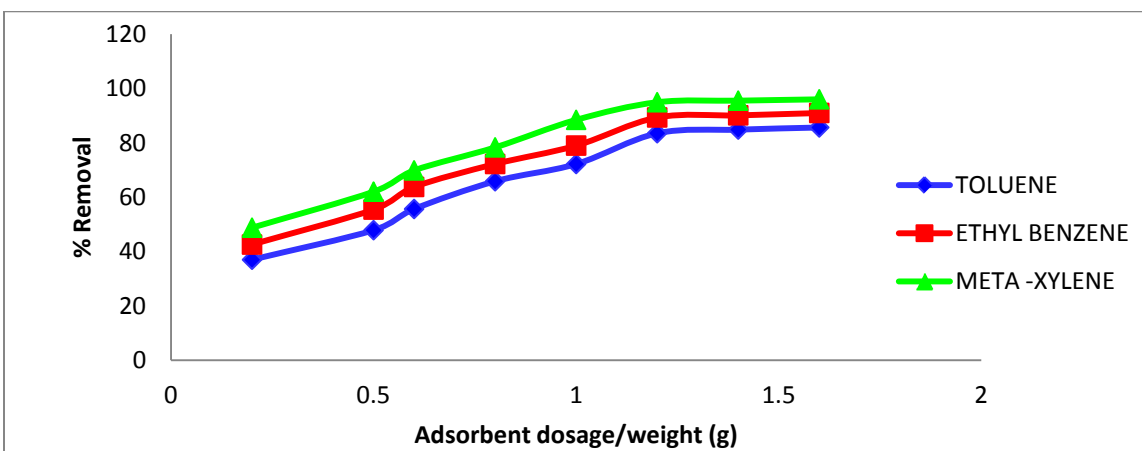


Figure 5. Effect of adsorbent weight on the percentage removal of meta- xylene, ethyl benzene and toluene using modified sodium bentonite.

### 3.2.3 EFFECT OF VARYING INITIAL CONCENTRATION

The effect of initial concentration is shown in figure 6. As the initial concentration increases, the amount (in percentage) of meta- xylene, ethyl benzene and toluene removed from the aqueous solution decreased. The decrease in the percentage removal is due to the fixed amount of adsorbent weight. This result is in resemblance with the result of the study conducted by Eman, 2013; Okiel *et al.*, 2011.

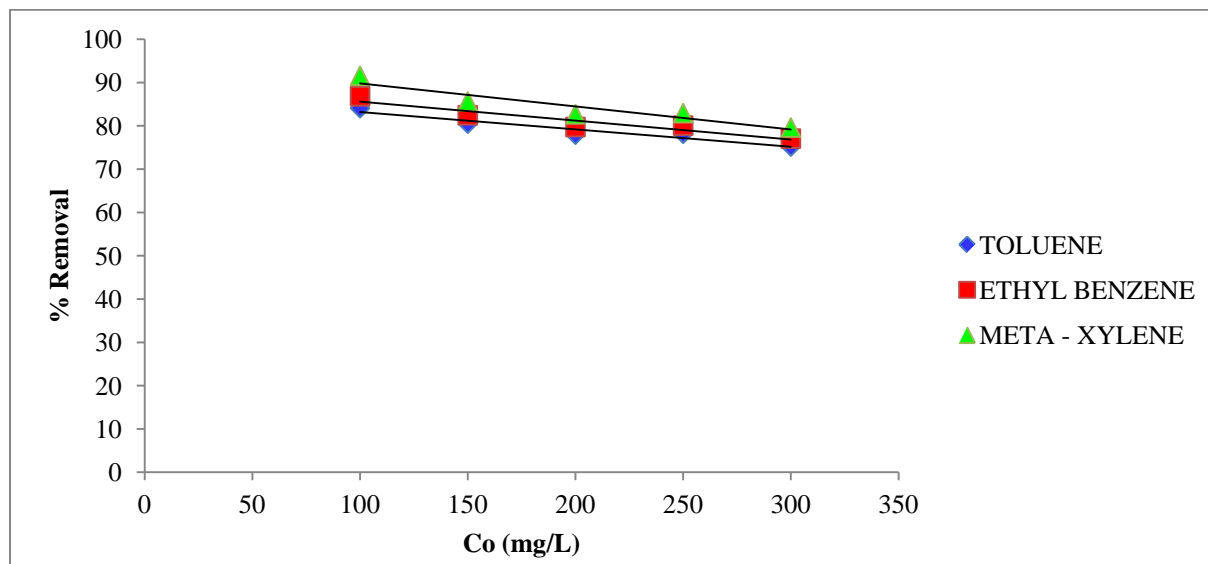


Figure 6. Effect of initial concentration on meta – xylene, ethyl benzene and toluene removal using Acid treated - modified sodium bentonite.

### 3.3 ADSORPTION ISOTHERM MODELS

Adsorption isotherm model refers to any graphical representation that can easily aid the study and the explanation of the adsorption processes. It could be regarded as any graphical expression which described the amount or the quantity of the adsorbate that has been adsorbed onto the surface of the adsorbent at a particular operating condition. Adsorption isotherms are precisely used to ascertain whether the adsorbent could be efficiently exploited for the removal of the adsorbate molecule from several solutions (Eman, 2013). The use of adsorption isotherm model helps one to understand the process of adsorption (Senturk *et al.*, 2009). The two widely used adsorption isotherm models include; Langmuir and Freundlich adsorption isotherm models. These two models could be used to determine whether adsorption will be favoured or not (Nourmoradi *et al.*, 2012; Senturk *et al.*, 2009).

#### 3.3.1 LANGMUIR ADSORPTION ISOTHERM MODEL

This is a mathematical isotherm model, which is being obtained from theoretical approach or non experimental analysis and also has a constant referred to as Langmuir constant. The Langmuir isotherm model assumes that the adsorption of adsorbate molecule can only occur at a homogeneous site of the adsorbent and when this happen, no other adsorption will take place on the adsorbent surface (Eman, 2013; Nourmoradi *et al.*, 2012; Senturk *et al.*, 2009).

Mathematically, the Langmuir adsorption isotherm model (Langmuir, 1918) is expressed as

$$\frac{C_e}{q_e} = \frac{C_e}{q_m} + \frac{1}{q_m K_L} \quad (5)$$

$C_e$  is the adsorbate concentration (mg/L) at equilibrium.  $q_e$ , which is the adsorption capacity (mg/g), refers to the quantity or amount of adsorbate removed or adsorbed from the solution per unit weight of the adsorbent.  $K_L$  is the Langmuir constant while  $q_m$  is the maximum capacity of the adsorbent (Langmuir, 1918). The values of  $k_L$  and  $q_m$  are obtained from a linear plot of  $C_e/q_e$  against  $C_e$ .  $K_L$  is the slope of the graph while  $q_m$  is the y-axis intercept. Langmuir separation factor,  $R_L$  is an important equilibrium parameter which helps to analyze the properties of the Langmuir isotherm model. The mathematical expression of the Langmuir separation factor,  $R_L$  (Hall *et al.*, 1966) is given as;

$$R_L = \frac{1}{1 + (K_L C_0)} \quad (6)$$

$K_L$  and  $C_0$  are Langmuir constant (L/mg) and the adsorbate's initial concentration (mg/L) respectively. If the separation factor,  $R_L = 0$ , adsorption is considered to be irreversible, if  $R_L = 1$ , it is considered to be linear but if  $R_L > 1$ , it is considered to be unfavorable. Adsorption is only considered to be favorable if  $1 > R_L > 0$ . (Eman, 2013; Senturk *et al.*, 2009). The Langmuir separation factor,  $R_L$  for meta- xylene, ethyl benzene and toluene removal using modified sodium bentonite obtained in this study are shown in table 1, which are given as 0.092, 0.156 and 0.182 respectively. This shows that the adsorption bonds between the adsorbate and the adsorbent are very strong and adsorption is greatly favoured since the  $R_L$  values are greater than 0 but less than 1.

### 3.3.2 FREUNDLICH ADSORPTION ISOTHERM MODEL

Freundlich isotherm model is an empirical adsorption isotherm model which explains the equilibrium relationships existing between the adsorbate and the adsorbent molecules and assumes multi layer adsorption on the adsorbent heterogeneous site. The Freundlich isotherm model (Eman, 2013; Koyuncu *et al.*, 2011) is given as;

$$\ln q_e = \ln k_F + \frac{1}{n} \ln C_e \quad (7)$$

$q_e$  and  $C_e$  are the adsorption capacity (mg/g) and the concentration (mg/L) of the adsorbate at equilibrium. The values of  $1/n$  and  $k_F$  are gotten from the linear plot of  $\ln q_e$  against  $\ln C_e$ .  $1/n$  is the slope of the graph while  $k_F$  is the intercept on y-axis, which are the Freundlich constant relating to heterogeneity of the adsorbent surface and adsorption capacity respectively.

The removal of meta – xylene, ethyl benzene and toluene from the aqueous solution shows a great affinity of the adsorbate towards the adsorbent and also a stronger interaction of the adsorbate – adsorbent molecules. The values of  $K_L$  and  $K_F$  are given in the order; meta – xylene



> ethyl benzene > toluene, which indicate the increasing solubility and hydrophilicity of the BTEX compound (adsorbate molecules).

Generally, the correlation factor,  $R^2$  obtained from the Freundlich isotherm model are quite closer to unity and also are higher than those of Langmuir isotherm as shown in table 1. The values of  $1/n$  are less than unity which shows a favourable adsorption process by the Freundlich adsorption isotherm. The data are best fitted with Freundlich adsorption isotherm model due to the proximity of the correlation factor,  $R^2$  to unity (1). This clearly indicates that Freundlich adsorption isotherm model best described the multi component adsorption of meta- xylene and toluene from the aqueous solution. Similar finding was also reported by some researchers such as Lin and Huang, 1999; Nourmoradi *et al.*, 2012; Sharmasarkar *et al.*, 2000 and Su *et al.*, 2010.

Table 1. Parameters of adsorption isotherm models

| Adsorption Isotherm Model |           | META-XYLENE |        | ETHYL BENZENE |        | TOLUENE |        |
|---------------------------|-----------|-------------|--------|---------------|--------|---------|--------|
|                           |           | ATMSB       | USB    | ATMSB         | USB    | ATMSB   | USB    |
|                           | Co (mg/L) | 300         | 300    | 300           | 300    | 300     | 300    |
| Langmuir                  | $q_m$     | 13.66       | 9.75   | 16.21         | 11.05  | 16.64   | 10.18  |
|                           | $K_L$     | 0.033       | 0.008  | 0.018         | 0.005  | 0.015   | 0.005  |
|                           | $R_L$     | 0.092       | 0.294  | 0.156         | 0.400  | 0.182   | 0.400  |
|                           | $R^2$     | 0.9199      | 0.9691 | 0.9307        | 0.9932 | 0.9442  | 0.9713 |
| Freundlich                | $K_F$     | 1.232       | 0.254  | 0.711         | 0.153  | 0.534   | 0.123  |
|                           | $1/n$     | 0.4901      | 0.6079 | 0.6035        | 0.6844 | 0.6574  | 0.7037 |
|                           | $R^2$     | 0.9746      | 0.9814 | 0.9918        | 0.9979 | 0.9935  | 0.9811 |

ATMSB = Acid Treated - Modified Sodium Bentonite, USB = Unmodified Sodium Bentonite.

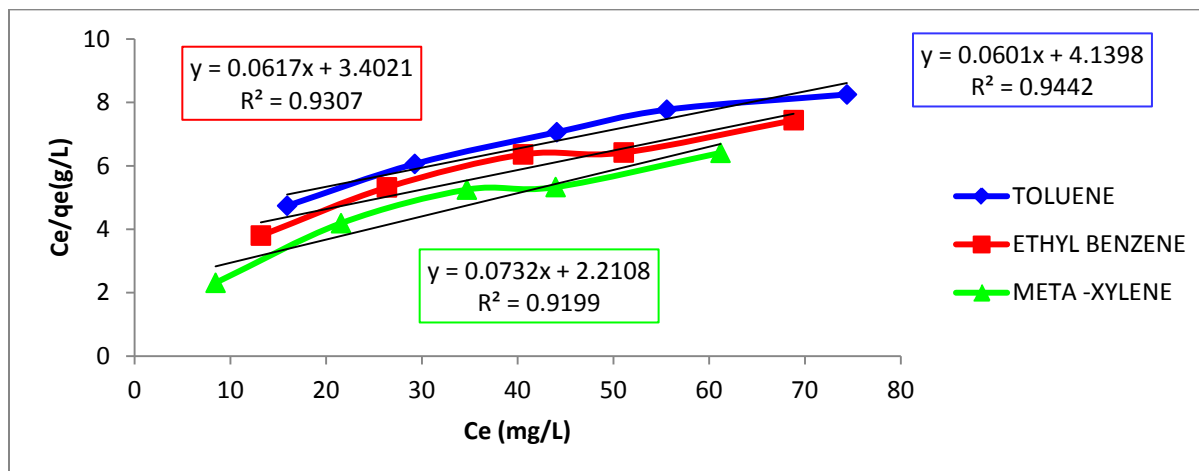


Figure 7. Langmuir Isotherm model for removal of toluene, ethyl benzene and meta -xylene from aqueous solution using Acid treated -modified Sodium bentonite.

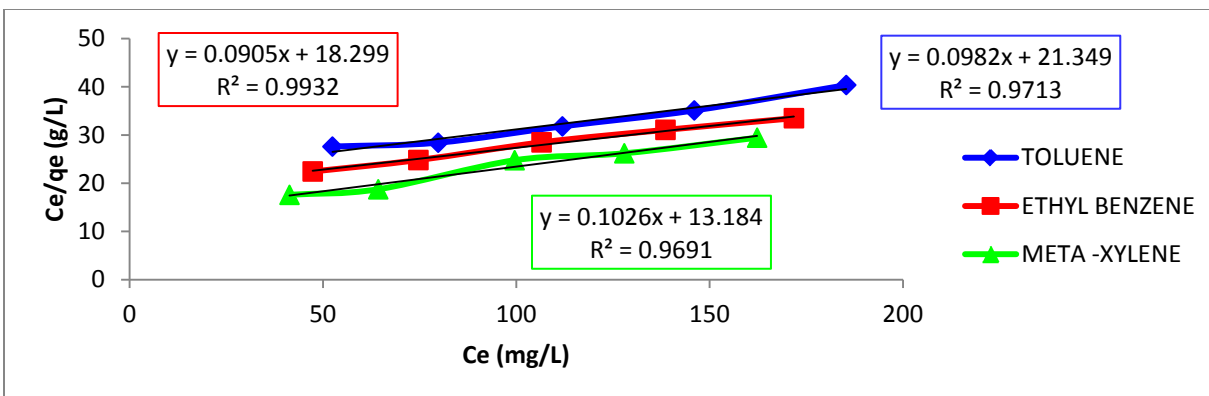


Figure 8. Langmuir Isotherm model for removal of toluene, ethyl benzene and meta -xylene from aqueous solution using unmodified Sodium bentonite.

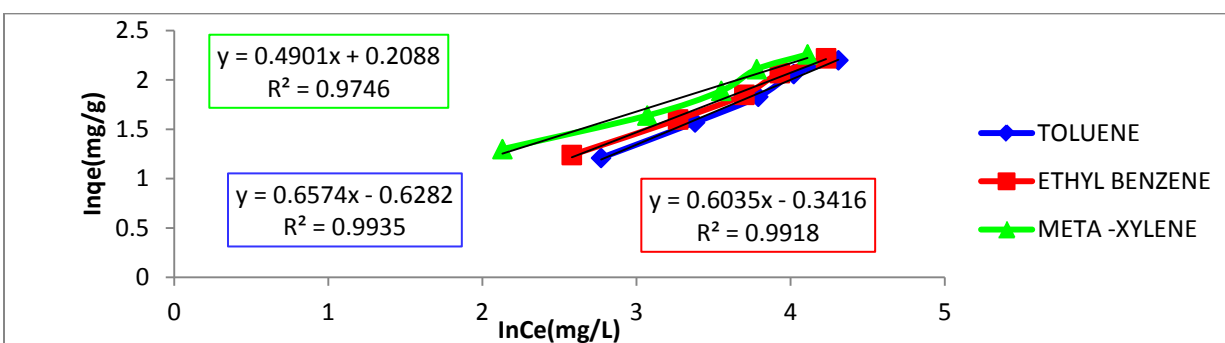


Figure 9. Freundlich Isotherm model for removal of toluene, ethyl benzene and meta -xylene from aqueous solution using Acid treated -modified Sodium bentonite.

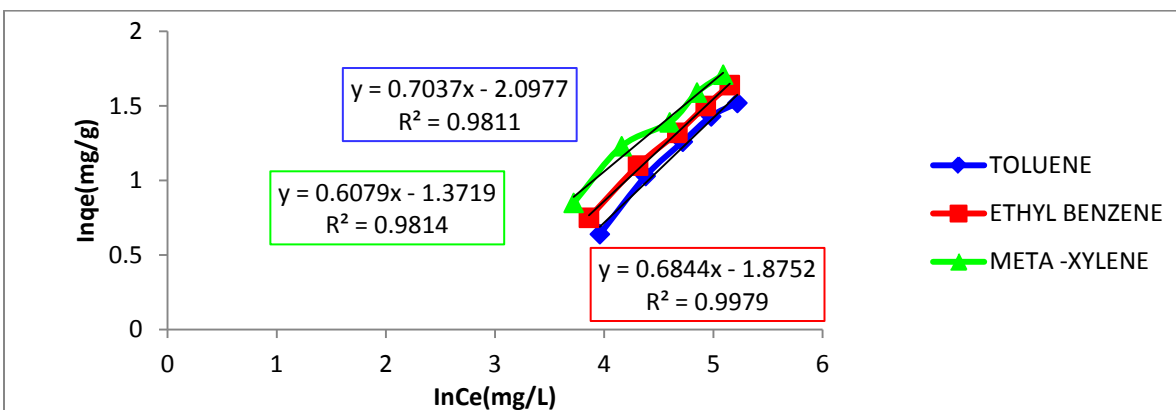


Figure 10. Freundlich Isotherm model for removal of toluene, ethyl benzene and meta -xylene from aqueous solution using unmodified Sodium bentonite.

### 3.4 ADSORPTION KINETICS MODELS.

These are important and necessary tools which are always exploited for the determination of adsorption processes. They are used to verify the effectiveness of the adsorbent under study. Three of these kinetic models that are often used are; Lagergren pseudo-first- order , pseudo-

second-order and intraparticle diffusion (Nourmoradi, *et al.*, 2012). Mathematically, the Lagergren pseudo- first- order kinetics model (Trivedi *et al.*, 1973) is expressed as;

$$\ln(q_e - q_t) = \ln q_e - k_1 t \tag{8}$$

$q_e$  and  $q_t$  are the adsorption capacity (mg/g) at equilibrium and at a specific time respectively.  $K_1$  and  $t$  are Lagergren rate constant for pseudo- first- order kinetics model and time in minutes. The values of  $k_1$  and  $q_e$  are obtained from a linear plot of  $\ln(q_e - q_t)$  against  $t$ .

Mathematically pseudo- second- order equation (Ho and Mckay, 1999) is expressed as;

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{t}{q_e} \tag{9}$$

$K_2$  is the rate constant for the pseudo- second order kinetics model. The value of  $k_2$  can be obtained from a linear plot of  $t/q_t$  against  $t$ .

The mathematical expression of the intraparticle diffusion kinetics (Su *et al.*, 2011) is written as;

$$q_t = k_{id} t^{1/2} + c \tag{10}$$

$K_{id}$  is the intraparticle diffusion constant and its value and that of  $c$  are obtained from a linear plot of  $q_t$  against  $t^{1/2}$ .

Considering the correlation factors,  $R^2$  in table 2, it's quite obvious that the data obtained are best fitted with pseudo- second- order kinetic model because they are closer to unity (1) compared to other models. The use of modified and unmodified sodium bentonite in the competitive adsorption of meta- xylene, ethyl benzene and toluene is best described by pseudo- second- order kinetics model. Meta- xylene was adsorbed higher than ethyl benzene, and the later was adsorbed higher than toluene due to their molecular weights differences. This is in line with the result obtained by Aivalioti *et al.*, 2012 and Nourmoradi, *et al.*, 2012 as shown in table 3.

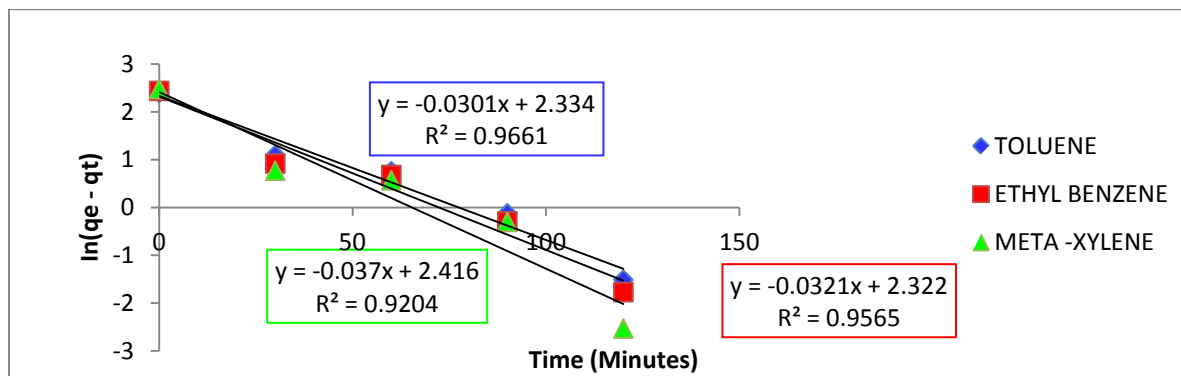


Figure 11. Lagergren Pseudo- first- order kinetics for the removal of toluene, ethyl benzene and meta -xylene from aqueous solution using Acid treated -modified Sodium bentonite.

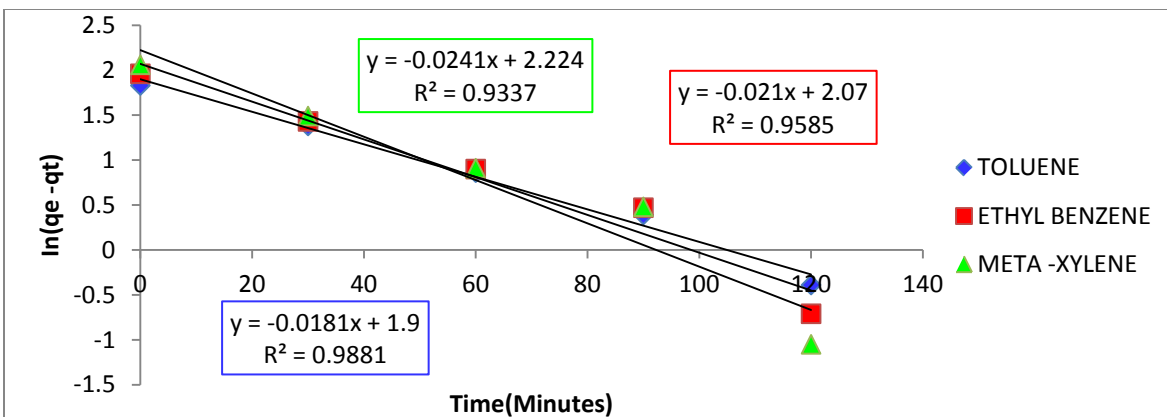


Figure 12. Lagergren Pseudo- first- order kinetics for the removal of toluene, ethyl benzene and meta -xylene from aqueous solution using unmodified Sodium bentonite.

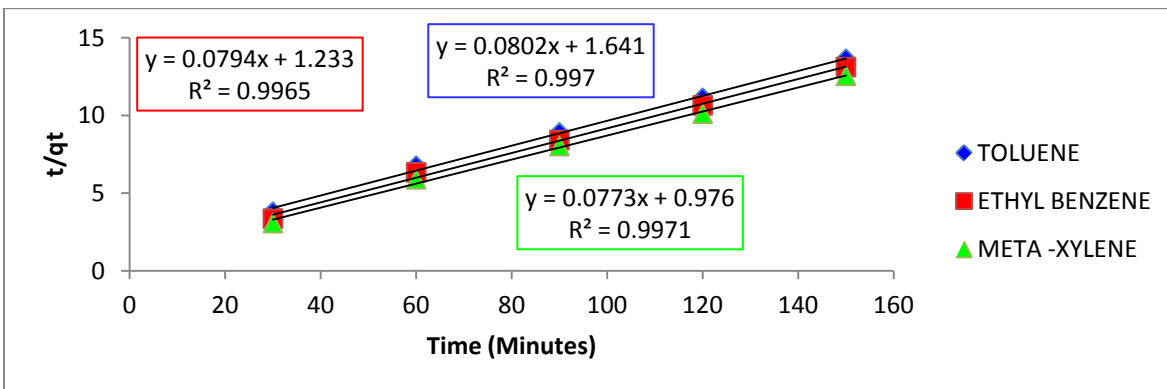


Figure 13. Pseudo-second order kinetic model for the removal of toluene, ethyl benzene and meta -xylene from aqueous solution using Acid treated -modified Sodium bentonite.

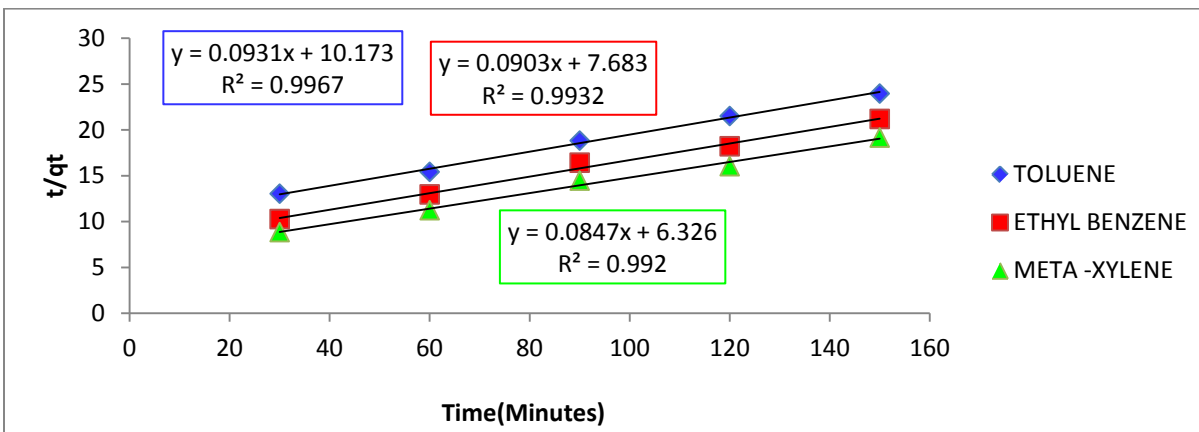


Figure 14. Pseudo-second order kinetic model for the removal of toluene, ethyl benzene and meta -xylene from aqueous solution using unmodified Sodium bentonite.

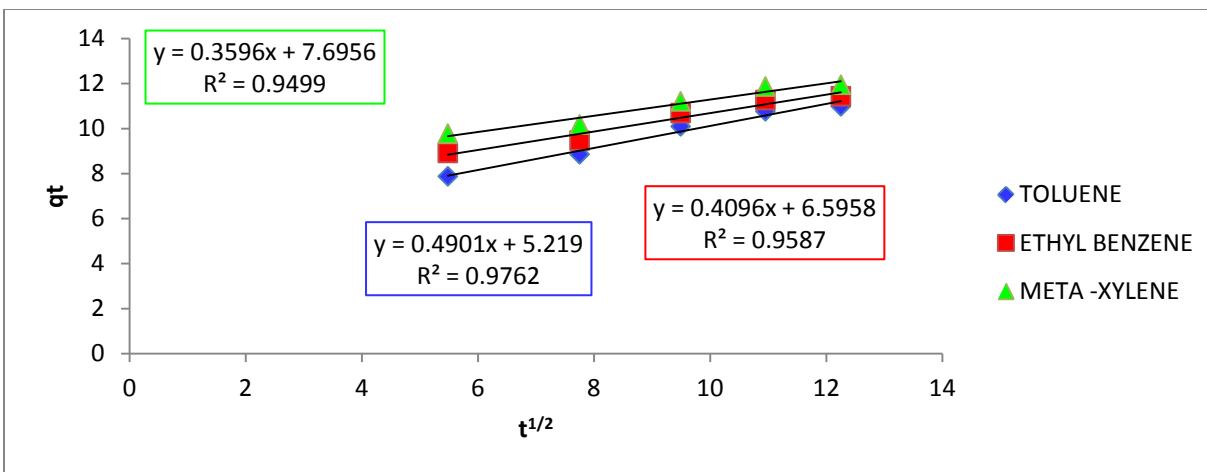


Figure 15. Intraparticle diffusion kinetic model for the removal of toluene, ethyl benzene and meta-xylene from aqueous solution using Acid treated -modified Sodium bentonite.

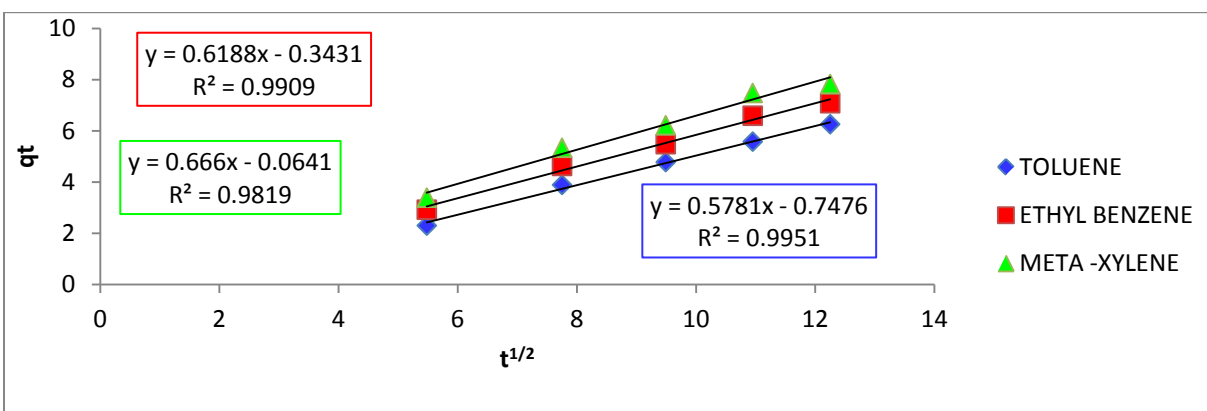


Figure 16. Intraparticle diffusion kinetic model for the removal of toluene, ethyl benzene and meta-xylene from aqueous solution using unmodified Sodium bentonite.

Table 2. Parameters for adsorption Kinetics models

| KINETICS MODEL                |                | META-XYLENE |        | ETHYL BENZENE |        | TOLUENE |        |
|-------------------------------|----------------|-------------|--------|---------------|--------|---------|--------|
|                               |                | ATMSB       | USB    | ATMSB         | USB    | ATMSB   | USB    |
|                               | Co (mg/L)      | 300         | 300    | 300           | 300    | 300     | 300    |
| Lagergren Pseudo- First Order | qe(mg/g)       | 11.95       | 7.83   | 11.44         | 7.08   | 10.99   | 6.26   |
|                               | K <sub>1</sub> | 0.037       | 0.024  | 0.032         | 0.021  | 0.0301  | 0.0181 |
|                               | R <sup>2</sup> | 0.9204      | 0.9337 | 0.9565        | 0.9585 | 0.9661  | 0.9881 |
| Pseudo- Second-Order          | qe(mg/g)       | 11.95       | 7.83   | 11.44         | 7.08   | 10.99   | 6.26   |
|                               | K <sub>2</sub> | 0.006       | 0.001  | 0.005         | 0.001  | 0.004   | 0.001  |
|                               | R <sup>2</sup> | 0.9971      | 0.9920 | 0.9965        | 0.9932 | 0.9970  | 0.9967 |

|               |              |        |        |        |        |        |        |
|---------------|--------------|--------|--------|--------|--------|--------|--------|
| Intraparticle | $q_e$ (mg/g) | 11.95  | 7.83   | 11.44  | 7.08   | 10.99  | 6.26   |
| Diffusion     | $K_{Id}$     | 0.3596 | 0.666  | 0.4096 | 0.6188 | 0.4901 | 0.5781 |
|               | $R^2$        | 0.9499 | 0.9819 | 0.9587 | 0.9909 | 0.9762 | 0.9951 |

ATMSB = Acid Treated Modified Sodium Bentonite, USB = Unmodified Sodium Bentonite.

Table 3. Comparism of the adsorption capacity of meta- xylene and toluene using different adsorbent.

| S/N |                  | $q_e$   |               |              | Reference                         |
|-----|------------------|---------|---------------|--------------|-----------------------------------|
|     |                  | Toluene | Ethyl benzene | Meta- xylene |                                   |
| 1   | HDTAB CLAY       | —       | -             | 9.328        | Obi and Apemiye, 2017             |
| 2   | ACTIVATED CARBON | 5.0     | -             | 6.5          | Daifullah <i>et al</i> , 2003.    |
| 3   | TTAB CLAY        | 5.15    | 6.0           | 6.98         | Aamir, 2017                       |
| 4   | DIATOMITE        | 0.037   | -             | 0.042        | Aivalioti <i>et al</i> , 2012     |
| 5   | HDTMA CLAY       | 6.8     | -             | 7.21         | Sharmasarkar <i>et al</i> , 2000. |
| 6   | AT -HDTAB CLAY   | 10.99   | 11.44         | 11.95        | This study                        |

HDTAB = Hexadecyltrimethylammonium bromide, TTAB = Tetradecyltrimethylammonium bromide, CTAB = Cetyltrimethylammonium bromide, AT -HDTAB = Acid treated - Hexadecyltrimethylammonium bromide

## CONCLUSION

The multi component adsorption of meta- xylene, ethyl benzene and toluene was carried out successfully using raw or unmodified and AT - HDTAB modified sodium bentonite. Modified sodium bentonite has a higher percentage removal and higher adsorption capacity than raw or unmodified sodium bentonite. Meta- xylene was removed from the solution more than ethyl benzene and the later was removed from the solution more than toluene. The percentage removal is given in the order meta – xylene > ethyl benzene > toluene. Acid treated - HDTAB modified sodium bentonite has proven to be an effective adsorbent for removal of BTEX compounds (meta- xylene, ethyl benzene and toluene) from their aqueous solution. Hence water treatment industries and petrochemical industries should utilize this adsorbent for the removal of these hydrocarbons from their waste water and effluents.

## ACKNOWLEDGEMENT

The authors wish to acknowledge the management of Mansid Nigeria Limited, Port Harcourt for providing the bentonite used for this research, the laboratory coordinator of Jawura environmental service limited Port Harcourt where the UV analysis was carried out, Energy research center, UNN, Comrade Olivia O. Ewuzie, Engr. Justice Arinze and Engr. Augustine M. Okeacha for their financial support. Our gratitude also goes to Prof. Ifedi P. Okoye and Dr. Temple N. Chikwe for their relentless effort, directions, contributions, knowledge and ideas.

## COMPETING INTERESTS

Authors have declared that no form of competing interest existed.

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