Batch study, equilibrium and kinetics of adsorption of naphthalene using waste tyre rubber granules

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Abstract

The potential use of waste tyre rubber granules (WTRG) for the batch adsorption of naphthalene from aqueous solutions was investigated. The effect of various operational variables such as contact time, initial naphthalene concentration, adsorbent dose, size of adsorbent particles, and temperature of solution on the adsorption capacity of WTRG was evaluated. The adsorption of naphthalene by WTRG was a fast kinetic process with an equilibrium contact time of 60 min. A low temperature (5°C), small adsorbent particle size (0.212 mm) and higher adsorbent dosage favored the adsorption process. Results of isotherm studies revealed that adsorption of naphthalene was best described by the Langmuir isotherm equation ($R^2=0.997$) while the kinetics of the process was best described by the Lagergren pseudo-first order kinetic equation ($R^2=0.998$). This study has demonstrated the suitability of WTRG for the removal of naphthalene from aqueous solution.

Introduction

Serious water pollution problems are still commonplace even in the face of the many existing environmental protection regulations. Naphthalene belongs to the family of hydrocarbons referred to as poly cyclic aromatic hydrocarbons (PAHs). These compounds enter the environment through two major avenues which are natural and anthropogenic. Natural sources of PAHs include volcanic eruptions and forest fires. They also enter the environment through a host of anthropogenic activities mainly incomplete combustion of fossil fuels for power generation.1–3 Naphthalene contaminated wastewater results from industrial and domestic effluents, leaks of PAHs containing materials such as petroleum fractions, creosote and pharmaceutical waste.4 The United States Environmental Protection Agency (USEPA) has classified naphthalene as non-commercial use only fuel for power generation.1–3 Naphthalene ties mainly incomplete combustion of fossil fuels through a host of anthropogenic activities and forest fires. They also enter the environment through two major avenues which are natural and anthropogenic. Natural contaminants such as creosote and pharmaceutical waste. Creosote and pharmaceutical waste. 4 The United States Environmental Protection Agency (USEPA) has classified naphthalene as a priority pollutant as a result of its carcinogenic and mutagenic effects on humans.5 Various methods for removing naphthalene from aqueous solutions including photocatalytic oxidation, biodegradation using surfactants, electron beam irradiation, ozonation and adsorption using zeolites and activated carbon have been reported.6–11 Adsorption remains the best option for the removal of naphthalene from solution as it can generally remove the compound in a simple and easy operation. However, the high cost associated with the use of activated carbon and other special adsorbents limits their applicability in treating large volumes of contaminated effluents.

An estimated 10 billion waste tyres are discarded annually worldwide.12 In Nigeria alone, the current estimate stands at about 21 million waste tyres which are discarded every year.13 These waste tyres represent a major environmental problem as only a small fraction of it is recycled to value added product such as floor mats, tyre derived fuels, liquid waste treatment, incorporation into asphalt for road pavement etc while the majority of it is often discarded inappropriately as it is done in developing countries.14,15 Alternative use instead of disposal appears to be a potentially sustainable solution to the environmental problem posed by the waste tyres.16 A lot of interest has been shown in the use of waste tyre rubber in the removal of organics from polluted wastewater.12,13,15–17 In comparison with conventional adsorbent, waste tyre rubber granules offers the advantage of being readily available and low cost. They have been applied to the treatment of contaminated effluents in different forms including waste tyre rubber granules, waste tyre rubber chips, waste tyre rubber ash, etc.

Kim et al.18 reported the sorption capacity of granulated waste tyre rubber for several aromatic hydrocarbons. They observed that the comparative adsorption capacity of granulated rubber tyres for the different compounds were in the order: m-xylene > ethylbenzene > toluene > trichloroethylene > 1,1,1-trichloroethane > chloroform. Park et al.19 used the data reported by Kim et al.18 to test a soil-bentonite slurry cutoff wall which contained ground tires to mitigate the movement of organic compounds in water. They observed that the rubber particles in the slurry wall and not the soil-bentonite were primarily responsible for the adsorption of the organic compounds. Aisien et al.20 investigated the influence of operational parameters on the adsorption of ethylbenzene using waste tyre rubber granules and determined that the adsorption capacity of waste tyre rubber granules (WTRG) for ethylbenzene was indeed affected by contact time, initial concentration, adsorbent dosage, adsorbent particle size and temperature.

This study investigated the potential use of WTRG for the adsorption of naphthalene from aqueous solution. The effects of factors such as contact time, initial naphthalene concentration, adsorbent dosage, adsorbent particle size and temperature on the adsorption process were evaluated. The adsorption of naphthalene on WTRG was further elucidated by carrying out kinetic (pseudo-first-order, pseudo-second-order, and intra particle diffusional) and isotherm studies using common isotherms such as Langmuir, and Freundlich isotherms.

Materials and Methods

Preparation of adsorbent

The waste tyres used for this study were collected from a waste tyre dumpsite in Uselu, Benin City, Nigeria. Dirt and other foreign materials were removed by washing the tyres with water and subsequently air-drying them. The cleaned sides of the tyre free from steel breeds were cut into sections with the aid of a hacksaw and later into small pieces using very sharp knives. The size of the tyre chips were further reduced using an electric grinding machine. The resulting tyre particles were mechanically sieved to obtain particles in the size range 2.36 to 0.212 mm using different sieve trays as shown in Table 1. The tyre granules were then washed with distilled water to remove any foreign materials by agitating it with a mechanical shaker operating at 150 rpm for 3 h. It was subsequently oven dried at 60°C.
for 5 h and stored in airtight containers for subsequent use.13 Nitrogen adsorption method was used to determine the surface area of the WTRG (BET 624; Micromeritics Germany GmbH, Aachen, Germany). Micropore volume was determined using the 3-D pore size distribution model developed at the Illinois State Geological Survey/University of Illinois at Urbana-Champaign (ISGS/UIUC) while the total pore volume was determined at a relative pressure value of approximately 0.98. Ultimate elemental analysis of the WTRG was carried out using standard American Society for Testing and Materials (ASTM) methods. The bulk density and porosity of the WTRG were determined using standard methods.20

Preparation of adsorbate

Analytical reagent grade naphthalene, provided by Griffin and George Ltd. (Loughborough, UK) was used as the representative PAH. A stock solution of naphthalene was prepared by dissolving 1 g of naphthalene in 1 L of a binary solution comprising 50 mL of methanol (British Drug Houses Ltd., London, UK) and 350 mL of de-ionized water. Naphthalene is a hydrophobic compound with low solubility in water. The water-methanol solution was used instead of pure de-ionized water to enhance the solubility of hydrophobic naphthalene.67 Working solutions of volume 100 mL with different concentrations of naphthalene were prepared by appropriate dilutions of the stock solution with distilled water immediately prior to their use. The dilutions were done by dispensing a quantity of the stock solution into 250 mL amber bottles according to Equation (1):

\[
C_1V_1 = C_2V_2
\]

(1)

where:

- \(C_1\) = concentration of standard solution (mg/L);
- \(V_1\) = volume from standard solution in (mL);
- \(C_2\) = required concentration in (mg/L);
- \(V_2\) = volume of required solution (100 mL).

Analysis of naphthalene in aqueous solution

A UV-Vis spectrophotometer (PG Instruments model T70) was used to determine the concentration of un-adsorbed naphthalene in the sorption medium at a wavelength of 276 nm.

**Results and Discussion**

Characterization of waste tyre rubber granules

The properties of WTRG as obtained from proximate analysis are presented in Table 2.21–23 Results of the ultimate elemental analysis of the WTRG are presented in Table 3.25–27 These results indicate that the principal constituent of WTRG was carbon which accounted for 86.5% of the weight of the granules followed by hydrogen which accounted for 6.64% as shown in Table 3. The inorganic ash content of the WTRG was about 3% as indicated in Table 3. The ash content is important because concentrations of trace species, especially metals, can affect the adsorptive properties of the WTRG. The values presented in Tables 2 and 3 are close to those reported in the literature. The surface area, bulk density, porosity, total and micro pore volume are presented in Table 4.

Effect of contact time on the adsorption of naphthalene by waste tyre rubber granules

Figure 1 shows the effect of contact time on the adsorption of naphthalene by WTRG. The trend observed show that the rate of adsorption was rapid initially and subsequently decreased to reach equilibrium after 60 min. At equilibrium, there is no noticeable increase in the rate of adsorption. This is because the adsorbent is saturated and all available active binding sites are occupied by the naphthalene molecules.13 The equilibrium contact time of 60 min indicates fast adsorption of naphthalene by WTRG. The fast adsorption rate observed at the initial stage might have been as a result of the abundantly available active binding sites on the adsorbent surface. These sites are subsequently occupied by naphthalene molecules thereby resulting in the inability of the WTRG to remove naphthalene consequently leading to the decreased adsorption rates observed at the later stages of the adsorption process.13,26,27 Similar results and observations have been reported in the literature. Agarry et al.1 reported an equilibrium time of 80 min for the adsorption of naphthalene by modified spent tea leaves. Gunasekara et al.6 reported fast adsorption of naphthalene, toluene and mercury by ground waste tyres with an equilibrium time of 30 min. Alam et al. reported an equilibrium contact time of 100 min for the abatement of organic pollutants such as 2,4-D and phenol using WTRG. An equilibrium contact time of 30 min was obtained for the removal of aromatic hydrocarbons such as ethylbenzene, toluene and xylene using granulated scrap tyre rubber as reported by Alamo-Nole et al.12 The structure and chemical composition of WTRG is a key determinant of its adsorptive properties. WTRG contains styrene amongst other functional groups. The aromatic ring in styrene enables interaction

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**Table 1. Rubber gradation.**

| Sieve size    | (% Passing) |
|---------------|-------------|
| 2.36 mm (48)  | 100         |
| 1.18 mm (16)  | 90          |
| 0.60 mm (30)  | 75          |
| 0.425 mm (40) | 50          |
| 0.212 mm (75) | 20          |

**Table 2. Properties of waste tyre rubber granules obtained from proximate analysis.**

| Property       | Present study | Lee et al.21 | Chang22 | Gonzalez et al.23 |
|----------------|---------------|--------------|---------|------------------|
| Fixed carbon   | 28.35         | 28.50        | 26.26   | 29.20            |
| Moisture       | 0.51          | 0.50         | 1.31    | 0.70             |
| Ash            | 7.60          | 3.7          | 10.29   | 8.0              |
| Volatile       | 63.54         | 67.30        | 62.32   | 61.90            |

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between styrene and naphthalene in aqueous solution. The increased affinity of the WTRG for naphthalene resulting from the interaction might explain the fast removal of naphthalene by WTRG.\textsuperscript{28}

**Effect of initial naphthalene concentration on the adsorption of naphthalene by waste tyre rubber granules**

The initial concentration of the adsorbate is an important factor that must be considered during adsorption as it affects the adsorption process to a large extent. The efficiency of WTRG in removing naphthalene from aqueous solution was presented in Figure 2. It was observed that the adsorption capacity of WTRG for naphthalene increased with increase in the concentration of naphthalene for all the concentrations studied. The trend observed might be due to the increase in the concentration gradient between the solid phase (adsorbent) and aqueous phase (adsorbate) which resulted from the increase in the concentration of naphthalene. The increased concentration gradient consequently leads to an increased driving force which overcomes the resistance to mass transfer between the solid and aqueous phases.\textsuperscript{13,29} Similar results have been reported in the literature. Alade \textit{et al}.\textsuperscript{30} reported an upward trend for the uptake of naphthalene using activated carbon. Mahvi \textit{et al}.\textsuperscript{27} reported similar trends for the uptake of phenol from aqueous solution using rice husk and rice husk ash. Agarry \textit{et al}.\textsuperscript{4} also indicated an increase in the adsorption of naphthalene with increase in concentration using spent tea leaves.

**Effect of adsorbent dosage on the adsorption of naphthalene by waste tyre rubber granules**

The effect of adsorbent dosage on the adsorption of naphthalene by WTRG is presented in Figure 3. In general, it was observed that the adsorption capacity increased with increase in adsorbent dosage indicating that the adsorbent dose had a significant influence on the adsorption process. Increasing the adsorbent dose resulted in an enhancement of the adsorption of

| Property  | Present study | Roy \textit{et al}.\textsuperscript{24} | Senneca \textit{et al}.\textsuperscript{25} | Gonzales \textit{et al}.\textsuperscript{23} |
|-----------|---------------|-----------------------------------|-----------------------------------|-----------------------------------|
| Carbon    | 86.50         | 86.6                              | 86.7                              | 86.7                              |
| Hydrogen  | 6.64          | 8.1                               | 6.9                               | 8.1                               |
| Oxygen    | 1.10          | 2.2                               | 1.0                               | 1.3                               |
| Nitrogen  | 0.40          | 0.5                               | 0.3                               | 0.4                               |
| Sulphur   | 2.0           | 0.8                               | 1.9                               | 1.4                               |
| Inorganic ash | 2.85       | -                                 | 3.3                               | 2.9                               |

**Figure 1.** Effect of contact time on the adsorption capacity of waste tyre rubber granules (WTRG) (pH 7; initial concentration, 800 mg/L; WTRG dose, 2 g; particle size, 0.212 mm; temperature, 20°C).

**Figure 2.** Effect of initial naphthalene concentration on the adsorption of naphthalene by waste tyre rubber granules (WTRG) (pH 7; WTRG dose, 2 g; particle size, 0.212 mm; temperature, 20°C).
naphthalene. This was probably as a result of the increase in the adsorptive surface area leading to the availability of more active binding sites.\textsuperscript{31,32} Zafar et al.\textsuperscript{33} reported that the amount of adsorbent added into the solution determines the number of binding sites available for adsorption. Mousavi et al.\textsuperscript{15} reported that the amount of adsorbent added into the solution determines the number of binding sites available for adsorption. Zafar et al.\textsuperscript{33} reported that the amount of adsorbent added into the solution determines the number of binding sites available for adsorption. Mousavi et al.\textsuperscript{15} reported enhanced uptake of lead ions from aqueous solution when the dose of waste tyre rubber ash was increased. Also, Aisien et al.\textsuperscript{34} reported the increased uptake of crude oil as the quantity of recycled rubber was increased.

**Effect of adsorbent particle size on the adsorption of naphthalene by waste tyre rubber granules**

Figure 4 shows the effect of adsorbent particle size on the adsorption capacity of WTRG for naphthalene. It was observed that the adsorption of naphthalene by WTRG increased with a decrease in the size of WTRG particles. The maximum adsorption capacity was observed at a particle size of 0.212 mm. The trend observed might be as a result of the increase in the interior surface area and micro pore volume and consequently more active sites for adsorption. However, for larger particles, the pore diffusion resistance to mass transfer is higher and most of the internal surfaces of the particle may not be utilized for adsorption and consequently the amount of naphthalene adsorbed is small.\textsuperscript{35} Smith et al.\textsuperscript{36} reported that smaller chips from recycled tyre rubber had higher adsorption capacity for phenol and p-cresol indicating the influence of adsorbent particle size and consequently the surface area on the sorption process. Aisien et al.\textsuperscript{13} reported similar results for the adsorption of ethylbenzene using WTRG. Agarry and Owabor\textsuperscript{26} also reported similar findings for the treatment of abattoir wastewater and removal of iron (III) ions using activated carbon made from rubber seed shells.

**Effect of solution temperature on the adsorption of naphthalene by waste tyre rubber granules**

The effect of temperature on the adsorption of naphthalene by WTRG is presented in Figure 5. The results show that the adsorption capacity of WTRG for naphthalene decreased from 19.99 to 15 mg/g with increase in temperature from 5 to 40°C. This indicated that a lower temperature was more favorable for the adsorption of naphthalene by WTRG. At low temperatures, the naphthalene molecules have less kinetic energy and will be able to migrate deeper into the WTRG micro-structure; hence more naphthalene will be retained by the adsorbent. However, at higher temperatures, the attractive force between the naphthalene molecules and the WTRG is weakened on the one hand and thermal energies of the naphthalene molecules are enhanced on the other hand thus making the attractive force between the naphthalene molecules and the WTRG insufficient to retain the adsorbed molecules at the binding sites.\textsuperscript{25} Mousavi et al.\textsuperscript{15} reported a similar trend and suggested that the inverse relationship between adsorption capacity and temperature is indicative of physical and exothermic adsorption.

**Modeling the kinetics of adsorption**

The kinetics of adsorption is useful in elucidating the mechanism of the adsorption process. The Lagergren pseudo first-order, pseudo second-order and intra particle diffusion kinetic models were applied to the data obtained for adsorption of naphthalene by WTRG.

**Lagergren pseudo first-order kinetic model**

The Lagergren rate equation is one of the most widely used kinetic equations for the adsorption of a solute from a liquid solution.\textsuperscript{38} The model assumes a first order adsorption kinetics of the form:

\[ \frac{dQ}{dt} = k(1 - \frac{Q}{Q_{e}}) \]

where \( Q \) is the amount of naphthalene adsorbed at time \( t \), \( Q_{e} \) is the amount of naphthalene adsorbed at equilibrium, and \( k \) is the rate constant.
kinetics and can be represented by the equation:

\[
\frac{d q_t}{d t} = k_1 (q_e - q_t)
\]

where:

- \( q_e \) and \( q_t \) are adsorption capacity at equilibrium and at time \( t \), respectively (mg/g);
- \( k_1 \) is the rate constant of pseudo first order adsorption (min\(^{-1}\)).

After integration and applying boundary conditions \( t=0 \) to \( t=t \) and \( q=0 \) to \( q=q_e \), the integrated form of Equation (4) becomes:

\[
\ln(q_e - q_t) = -k_1 t
\]

The values of \( \ln(q_e - q_t) \) were plotted as a function of \( t \). The plot of \( \ln(q_e - q_t) \) versus \( t \) resulted in a linear relationship as shown in Figure 6 from which \( k_1 \) and \( q_e \) were determined from the slope and intercept respectively. The first order rate constants calculated from the plot are given in Table 5.

**Pseudo second-order kinetic model**

The pseudo-second order kinetic model which is based on the assumption that chemisorption is the rate-determining step can be expressed as in Equation (6):

\[
\frac{d q_t}{d t} = k_2 (q_e - q_t)^2
\]

where:

- \( k_2 \) is the rate constant of the pseudo second order adsorption (g.mg\(^{-1}\).min\(^{-1}\)).

After integration and applying boundary conditions \( t=0 \) to \( t=t \) and \( q=0 \) to \( q=q_e \), the integrated form becomes:

\[
\frac{1}{q_e - q_t} = \frac{1}{q_e} + k_2 t
\]

Equation (7) can be rearranged to a linear form as shown in Equation (8).

\[
\frac{t}{q_t} = \frac{1}{h} + \frac{1}{q_e}
\]

The initial adsorption rate, \( h \) (mg.g\(^{-1}\).min\(^{-1}\)) is given as:

\[
h = k_2 q_e^2
\]

The plot of \( (t/q_t) \) and \( t \) of Equation (8) as presented in Figure 7 resulted in a linear relationship from which \( q_e \) and \( k_2 \) were calculated. These values are given in Table 5.

**Intra particle diffusion model**

The intra particle diffusion kinetic model\(^{39}\) can be written as presented in Equation (10):

\[
q_t = K_p t^{1/2} + C
\]

\( K_p \) is the intra particle diffusion rate constant (mg.g\(^{-1}\).min\(^{-1/2}\)) and \( C \) is the intercept of the plot which is indicative of the boundary layer thickness. If the intercept is greater than zero, it indicates the existence of some boundary
layer effect and shows that intra-particle diffusion is not the only rate-limiting step. This was indeed the case for the $q_t$ versus $t^{1/2}$ plot presented in Figure 8. The calculated diffusion coefficient values are presented in Table 5.

In this study, the Lagergren pseudo first order and pseudo second order kinetic models fitted well to the adsorption kinetic data with relatively high correlation coefficients. However, the intra particle diffusion kinetic model did not result in a good fit with the data as seen in the lower value of the correlation coefficient. The Lagergren pseudo first-order model gave the best fit with the highest correlation coefficient to describe the adsorption behaviour of naphthalene by WTRG.

**Isotherm studies**

Adsorption isotherms were used to describe the equilibrium between the concentration of naphthalene in the aqueous phase and that in the solid (adsorbent) phase. A number of isotherm equations have been developed to describe equilibrium relationships. The Langmuir and Freundlich isotherm equations were utilized for this study.

**Langmuir isotherm**

The Langmuir isotherm equation is applied for monolayer adsorption onto an adsorptive surface containing homogeneously distributed active sites. The equation contains two useful parameters ($q_o$ and $b$), which reflect the two important characteristics of the sorption system. It provides information on uptake capabilities and is capable of reflecting the usual equilibrium adsorption process behavior. The linear form of the Langmuir equation is given as:

$$\frac{C_e}{q_t} = \frac{1}{q_o b} + \frac{C_e}{q_o}$$  \hspace{1cm} (11)

$q_o$ is the maximum sorption capacity (mg/g) of the adsorbent while $b$ is the sorption constant (L/mg) at a given temperature. A linear plot of $C_e/q_t$ against $C_e$ as shown in Figure 9 was employed to obtain the values of $q_o$ and $b$ from the slope and intercept of the plot respectively. The values of the Langmuir isotherm parameters as well as the correlation coefficient ($R^2$) of the Langmuir equation for the adsorption of naphthalene by WTRG are given in Table 6. The values of these parameters were close to those reported by Agarry et al. and Tsyntsarski et al. for the adsorption of naphthalene by spent tea leaves and activated carbon produced from biomass and coal wastes respectively. The separation factor ($R_L$) can be used to describe the characteristics of the Langmuir isotherm equation. The value of this dimensionless constant defined in Equation (12) determines whether the adsorption process is favorable or otherwise.

$$R_L = \frac{1}{1 + bC_i}$$  \hspace{1cm} (12)

$C_i$ is the initial concentration of naphthalene.

The dependence of the nature of adsorption on the value of $R_L$ is presented in Table 7.

For the present study, the values of $R_L$ obtained at different initial naphthalene con-

![Figure 7. Pseudo second order kinetic model fitted to the batch adsorption data obtained for naphthalene adsorption by waste tyre rubber granules.](image1)

![Figure 8. Intra particle diffusion model fitted to the batch adsorption data obtained for naphthalene adsorption by waste tyre rubber granules.](image2)
centrations are presented in Table 8. These values are between zero and one indicating that the adsorption was favorable.

**Freundlich isotherm**

The Freundlich isotherm is an empirical equation employed to describe heterogeneous systems. It is expressed in its non-linear form as:

\[ q_e = K_f (C_e)^{1/n} \]  

(13)

This equation can be expressed in linear form as follows:

\[ \ln q_e = \ln K_f + \frac{1}{n} \ln C_e \]  

(14)

where \( K_f \) and \( n \) are the Freundlich constants related to the adsorption capacity and adsorption intensity respectively. These parameters were determined from the intercept and slope of the linear plot of \( \ln q_e \) against \( \ln C_e \) at given experimental conditions as shown in Figure 10. Values of \( n \) between 1 and 10 represent favorable adsorption.4 The values of these parameters as well as the correlation coefficient (R²) of the Freundlich equation for the adsorption of naphthalene by WTRG are given in Table 6.

Values of \( K_f \) and \( n \) have been reported in the literature. Pal44 reported \( K_f \) and \( n \) values of 0.3 and 1.12, 0.025 and 1.47 for the adsorption of naphthalene by sugarcane bagasse and rice husk respectively. Agarry et al.4 reported \( K_f \) and \( n \) values 2.44 and 1.85 respectively.

Generally, the results presented in Table 6 indicate that the adsorption data fitted both the Langmuir and Freundlich isotherm equations. However a better fit resulted for the Langmuir isotherm equation as evident in the higher R² value obtained. This suggests that the adsorption of naphthalene by WTRG is of the mono-layer type. Similar observations have been reported for the adsorption of aromatics by WTRG and other adsorbents.4,7,13,41

**Conclusions**

The present study investigated the potential use of waste tyre rubber granules for the batch adsorption of naphthalene from aqueous solutions. The following conclusions can be drawn.

- Adsorption of naphthalene by WTRG is influenced by factors such as contact time, initial naphthalene concentration, adsorbent dosage, adsorbent particle size and solution temperature.
- The equilibrium contact time was obtained as 60 min indicating a fast adsorption process.
- A low temperature (5°C), small adsorbent particle size (0.212 mm) and higher adsorbent dosage favored the adsorption process with removal capacities of 19.99, 20 and 26.32 mg/g respectively.

**Table 7.** \( R_L \) values and type of isotherm.

| \( R_L \) | Type of isotherm  |
|----------|-------------------|
| \( R_L > 1 \) | Unfavorable       |
| \( R_L = 1 \) | Linear            |
| \( 0 < R_L < 1 \) | Favorable         |
| \( R_L = 0 \) | Irreversible      |

\( R_L \), separation factor.

**Table 8.** \( R_L \) values and type of isotherm.

| Initial concentration (mg/L) | \( R_L \) value |
|-----------------------------|---------------|
| 100                         | 0.154         |
| 200                         | 0.083         |
| 300                         | 0.057         |
| 400                         | 0.043         |
| 500                         | 0.035         |
| 600                         | 0.029         |
| 700                         | 0.025         |
| 800                         | 0.022         |

\( R_L \), separation factor.
- The adsorption equilibrium data fitted well to the Langmuir isotherm equation indicating mono layer type adsorption.
- The kinetics of the adsorption process was well described by the Lagergren pseudo-first order kinetic model.
- This study has demonstrated that the low cost WTRG can be used for removal of naphthalene from aqueous solution.

Research highlights

The amount of waste tyre generated annually in Nigeria is on the increase as a result of the increase in vehicular traffic. These waste tyres are typically disposed of inappropriately thereby constituting environmental problems. Naphthalene is a toxic organic pollutant found in most industrial effluents. This research work aims to add value to waste tyres by using it in granulated form as an adsorbent for the removal of naphthalene from aqueous solutions.

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