Packed-Bed Column Adsorption of Metanil Yellow (MY) from Simulated Wastewater using Granular NaOH-Activated Carbon from Cassava (Manihot esculenta) Peels

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ABSTRACT

The ability of NaOH-activated carbon derived from cassava peels waste to remove MY from aqueous solution was carried out in a fixed-bed column adsorber. The parameters studied included initial solution concentration, \( C_0 \), carbon bed height and volume flow rate. The temperature of operation and initial solution pH were 29 °C and 5.32 respectively. The optimum adsorption capacity, \( q_e \) 4.12 mg/g was obtained at \( C_0 \) 10mg/L, bed height 10cm and flow rate, 13.3ml/min. Experimental data were analyzed with Langmuir, Freundlich and Temkin isotherm, as well as the Thomas, Yoon-Nelson and Clark kinetic models. All the models were good fits for experimental data based on correlation coefficient, \( R^2 \) values. The \( \Delta G_{ads} \) and Freundlich \( n \) (1.587) show that the biosorption was spontaneous, good and physical. Results show that NaOH-activated carbon from cassava peels has low capacity in the removing MY from aqueous solution.

Keywords: Adsorption, cassava peels, fixed-bed, metanil yellow, modeling
1. INTRODUCTION

Urbanization and industrialization contribute to a large extent in environmental pollution. In many parts of the world especially in developing countries, polluted water is discharged into streams, wells, rivers and other water bodies without proper treatment (Nwabanne and Igboke). Pollution from wastewater deprecates land values, increases municipal costs and causes numerous harmful biological and health effects (Ong et al., 2007). Azo dyes are widely used in textile dyeing, paper printing and other industrial processes such as manufacture of pharmaceutical drugs, toys and foods. Dyes characterized by the presence of at least one azo linkage (-N=N-) bearing aromatic rings, dominates the worldwide market of dyestuffs with a share of about 70% (Ahmad and Hameed, 2010; Osma et al., 2007; Soares et al., 2002).

MY is an azo, water-soluble dye. Although it is a non-permitted colour, it is still widely used as a colorant in sweet meat, ice creams, soft drinks and beverages. Due to its orange yellow colour, MY is extensively used for coating turmeric. It is widely used in colouring leather, paper and in textile industries and also as a stain and colorant for wool. It is used in colouring lacquers and cosmetic products. The dye is suitable for preparing water-fast inks (Mittal et al., 2008; Zimmerman, 1933). Toxicity data reveals that oral feeding of intraperitoneal and intratesticular administration of MY in animals produces testicular lesions due to which seminiferous tubules suffer damage and rate of spermatogenesis is decreased. On oral consumption, it causes toxic methaemoglobinaemia (Sachdeva et al., 1992) cyanosis (Chandro and Nagaraja, 1987) in humans, while skin contact results into allergic dermatitis (Hausen, 1994). MY creates intestinal (Ramchandani et al., 1997) and enzymic (Das et al., 1997) disorders in the human body. It is not mutagenic but can alter the expression genes (Gupta et al., 2003).

Removal of toxic industrial, water-soluble non-biodegradable wastes, particularly organic dyes is of great concern. Hence, removal of coloured wastes from wastewater is of significant importance. Physicochemical oxidation, froth floatation, etc., have been used for the removal of organics as well as inorganics from wastewater (Mittal et al., 2008). Using sophisticated instruments, electrochemical processes like electrochemical degradation (Fan et al., 2006), electro-coagulation (Daneshvar et al., 2006), electrochemical oxidation (Rajkumar and Kim, 2006) and photoelectrocatalytic methods (Ahmad and Hameed, 2010; Gupta et al., 2007), the task to eradicate toxic pollutants from water have been accomplished. Adsorption is considered one of the most efficient due to its easy methodology and operations. Activated carbon (AC) is a widely used adsorbent in the treatment of wastewater because it possesses desirable physicochemical properties including good mechanical strength, chemical stability in diverse media, and large pore size distribution in addition to its extensive specific surface area (Zhu and Yuan, 2011). Because commercial ACs are expensive, emphasis is currently placed on the preparation of low-cost ACs from agricultural by-products, which are from renewable sources (Salman et al., 2011; Ren et al., 2011; Li et al., 2010; Petrov et al., 2010; Sun and Webley, 2010; Dolas et al., 2011; Baccar et al., 2010). Investigations have been carried out to remove contaminants from wastewater using fixed-beds. Batch adsorption data are generally not applicable to most treatment systems (such as column operations) where contact time is not sufficient for the attainment of equilibrium. Packed - bed column operation is preferred to the batch operation for the removal of micropollutants when dealing with large volumes of wastewater (Banat et al., 2007).
The aim of this work was to produce activated carbon from cassava peels and explore its efficacy in the removal of MY in a fixed-bed column. The effects of $C_o$, carbon bed height and dye solution volume flow rate were studied.

2. MATERIALS AND METHODS

The MY (Merck) used in this work, was purchased at Onitsha, Nigeria and used with no further treatment. Fig. 1 shows the structure. Stock solution was prepared by dissolving 1g per litre solution using distilled water.

2.1 Preparation of activated carbon

The method of Pokordi and Vasant Kumar, (2006) was used. The cassava peels used in this work was obtained from Egbeada in the Mbatisol Local Government Area of Imo State, Nigeria. The biomass was washed to remove dirt and soil, and dried in a hot-air oven. The dry biomass was carbonized at 500 °C for 7h and cooled. The char was ground and sieved to get 0.595 – 1.68 mm size particles, which were impregnated with 4.17% NaOH solution at a ratio of 1 char: 3 alkali w/w. Excess alkali was drained off after 24h. The carbon was dried and heated at 500 °C for 4h. After cooling, the carbon was leached with hot distilled water to pH ≈6. The carbon was dried in a hot-air oven at 110 °C for 2h. It was cooled and packaged in an airtight plastic container. The AC was analyzed for physicochemical properties.

2.2 Fixed-bed adsorption process

The fixed-bed column was made of Pyrex glass cylinder 1cm inner diameter and 43cm length. The method of Ahmad and Hameed, (2010) was used. The bottom of the column was plugged with glass wool. A known mass of AC equivalent to 10, 20 or 30 cm height was packed in the column and the carbon sealed with glass wool. Glass beads were introduced to occupy the space above the carbon. This enhanced uniform flow of the adsorbate. Dye solution of $C_o$ (10, 50 or 100 mg/L) at pH 5.32 was pumped upward with a metering pump (Chem-Tech Pal No. 0-111.808) at a known flow rate (13.3, 25 or 34 ml/min), and temperature 29 °C. Effluent samples were collected at regular intervals of 30min and analyzed with a UV/Vis spectrophotometer (Shimadzu UV-752, Japan) at $\lambda_{max}$ 440nm. Different $C_o$ were got by diluting the stock solution with distilled water.

2.3 Characterization of activated carbon

The bulk and dry densities, and porosity were determined by the method of Ekpete et al., (2012); pore volume by the method of Mohammed et al., (2012); specific surface area by the ethylene glycol monoethyl ether (EGME) method (Cerator and Luteneger, 2002); Iodine number by the method of Gimba and Musa, (2005); pH by the ASTM D 3838 – 80 standard test method, (1996); moisture, volatile matter, ash, and fixed carbon contents by the methods of Rengaraj et al., (2002); AOAC, 1990; Isiuku et al., (2015) respectively.
2.4. Fixed-bed column adsorption analysis

The time for breakthrough appearance and the shape of the breakthrough curve are paramount in determining the operation and the dynamic response of an adsorption packed-bed column. The breakthrough curves show the loading behaviour of the dye to be removed from solution in a packed-bed column and is usually expressed in terms of adsorbed dye concentration $C_{ad}$, or normalized concentration $C_{t}/C_{o}$, as a function of time or volume of effluent for a given bed height (Ahmad and Hameed, 2010; Isiuku et al., 2014; Aksu and Gönen, 2004; Taty-Custodes et al., 2005). Effluent volume $V_{eff}$, can be calculated from Eq. 1:

$$V_{eff} = Qt_{tot}$$

where: $t_{tot}$ (min) is the total flow time. The area under the breakthrough curve $A$, obtained by integrating the adsorbed concentration $C_{ad}$ (mg/L) against time (min) plot can be used to find the total adsorbed dye quantity $q_{tot}$ (mg). $q_{tot}$ for a given $C_{o}$ and flow rate is calculated from Eq. 2:

$$q_{tot} = \frac{QA}{1000} = \frac{Q}{1000} \int_{t_{o}}^{t_{tot}} C_{ad} \, dt$$

Total amount of dye sent to the column $m_{tot}$ is determined from Eq. 3:

$$m_{tot} = \frac{C_{o}q_{tot}}{1000}$$

Total removal R (%) of dye (column performance) with respect to flow volume can be determined from the ratio of $q_{tot}$ to $m_{tot}$, Eq. 4:

$$R(\%) = \frac{100q_{tot}}{m_{tot}}$$

Equilibrium uptake of the dye in the column per unit mass of dry adsorbent $x$ (g), $q_{e}$ (mg/g) is defined by Eq. 5 as:

$$q_{e} = \frac{q_{tot}}{x}$$

Un-adsorbed dye concentration at equilibrium in the column $C_{e}$ (mg/L) is given by Eq. 6:

$$C_{e} = \frac{(m_{tot} - q_{tot})1000}{V_{eff}}$$

$$C_{e} = \frac{(m_{tot} - q_{tot})1000}{Qt_{tot}}$$
2. 4. 1. Isotherm modelling

Adsorption isotherms portray the distribution of adsorbate particles between the liquid phase and the solid phase as the adsorption reaches equilibrium (Bello et al., 2012). In this work, experimental results were analyzed with the Langmuir, Freundlich and Temkin isotherm models.

2. 4. 1. 1. Langmuir isotherm model

The Langmuir isotherm is based on the assumption that a fixed number of adsorption sites are available, and the adsorption is reversible. The model also assumes that the surface of the adsorbent is homogenous (Nidheesh et al., 2012). The model equation is expressed as Eq. 8:

\[ q_e = \frac{q_mC_L C_e}{1 + K_L C_e} \]  

The linear form of Eq.8 is expressed as Eq.9:

\[ \frac{1}{q_e} = \frac{1}{q_m} + \left( \frac{1}{q_m K_L} \right) \frac{1}{C_e} \]  

where: \( K_L \) (L/g) is a constant that increases with increasing particle size, \( q_m \) (mg/g) is the amount of adsorbate adsorbed to form a complete monolayer on the adsorbent surface. A plot of \( 1/q_e \) vs \( 1/C_e \) gives a straight line with slope and intercept equal to \( 1/q_m K_L \) and \( 1/q_m \) respectively.

The favourability of the biosorption process was confirmed (Bello et al., 2012) by applying the separation factor \( R_L \) expressed as Eq. 10:

\[ R_L = \frac{1}{1 + K_L C_{om}} \]  

where: \( C_{om} \) is the maximum influent concentration.

2. 4. 1. 2. Freundlich isotherm model

The Freundlich isotherm is based on non-ideal biosorption that involves heterogeneous surface energy systems. It is expressed (Dutta et al., 2012) in the logarithmic form as Eq. 11:

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

where: \( K_F \) is the Freundlich constant which is a rough indicator of the biosorption capacity and \( 1/n \) is the biosorption intensity. A plot of \( \ln q_e \) vs \( \ln C_e \) gives a straight line with slope equal to \( 1/n \) and intercept equal to \( \ln K_F \).
2.4.1.3. Temkin isotherm model

The Temkin model describes the heat of biosorption and interaction between biosorbate and biosorbent particles (Dutta et al., 2012). It is expressed as Eq. 12:

\[ q_e = \frac{RT}{b_T} \ln A_T + \frac{RT}{b_T} \ln C_e \]  

(12)

where: \( A_T \) and \( b_T \) are Temkin constants. Plots of \( q_e \) vs \( \ln C_e \) gives a straight line, with slope equal to \( RT/b_T \), and intercepts equal \( (RT/b_T) \ln A_T \).

2.4.2. Column adsorption modelling

To design a column adsorption process, it is vital to predict the breakthrough curve and adsorption capacity of the adsorbent for the selected adsorbate under the given set of operating conditions. It is also important for determining maximum column adsorption capacity which is important to any adsorption system (Isiuku et al., 2014; Patel and Vashi, 2012).

Mathematical models have been developed for the determination of efficiency and applicability of the column models for large scale operations. They include the Thomas and Yoon-Nelson models which were applied in this study.

2.4.2.1. The Thomas model

The Thomas model (Nidheesh et al., 2012) is one of the most commonly used models in fixed-bed column adsorption process. It is expressed as Eq. 13:

\[ \frac{C_t}{C_o} = \frac{1}{1 + \exp\left[K_{Th}(q_o 1000x - C_o V_{eff})/Q\right]} \]  

(13)

where: \( C_t \) (mg/L) is the effluent dye concentration at time, \( t \) (min), \( K_{Th} \) (ml/mg/min) is the Thomas rate constant and \( q_o \) (mg/g) is the estimated adsorption capacity of the adsorbent.

The value \( V_{eff} \) can be obtained by the expression Eq. 14:

\[ V_{eff} = Q t_{tot} \]  

(14)

The linearized form of the Thomas equation is expressed as Eq.15:

\[ \ln \left(\frac{C_o}{C_t} - 1\right) = \frac{K_{Th} q_o 1000x}{Q} - K_{Th} C_o t \]  

(15)

Figs 5-7 show plots of \( \ln [(C_o/C_t) - 1] \) against \( t \) that are straight lines for various \( C_o \) (at fixed bed height and flow rate), bed height (at fixed \( C_o \) and flow rate) and flow rate (at fixed \( C_o \) and bed height). Table 2 shows the Thomas parameters at various conditions. The values show that as \( q_o \) increased, the rate constant decreased. Also, \( q_o \) increased with increase in \( C_o \), increase in bed height and decrease in flow rate. The result agrees with literature (Ahmad and Hameed, 2010). The \( R^2 \) values show that Thomas model fitted experimental data well.
2. 4. 2. 2. The Yoon-Nelson model

The linearized form of the Yoon-Nelson model (Salman et al., 2011) is expressed as Eq. 16:

\[
\ln\left[\frac{C_t}{(C_o - C_t)}\right] = K_{YN} - \tau K_{YN} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (16)
\]

where: \( K_{YN} \) (L/min) is the Yoon-Nelson constant, \( \tau \) (min) is the time required for 50% adsorbate breakthrough, and \( t \) (min) is the sampling time.

Figs 8-11 show plots of \( \ln[C_t/(C_o-C_t)] \) against \( t \) for different \( C_o \) (at fixed bed height and flow rate), bed heights (at fixed \( C_o \) and flow rate) and flow rate (at fixed \( C_o \) and bed height). Straight lines were obtained from which \( K_{YN} \) values were determined from the intercepts and \( \tau \) values from the slopes (Table 4). The \( q_o \) from the Yoon-Nelson model (Patel and Vashi, 2012; Sivakumar and Palanisamy, 2009b) was determined from Eq. 17:

\[
q_o = \frac{q_{tot}}{x} = \frac{C_o Q \tau}{1000 x} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (17)
\]

The \( R^2 \) values show that the Yoon-Nelson model simulated experimental data well. Table 4 also shows increase in \( q_o \) with increase in \( \tau \), increase in bed height and decrease in flow rate. \( q_o \) increased with decrease in \( K_{YN} \). These results have the same trend with literature (Ahmad and Hameed, 2010).

2. 4. 2. 3. Clark Kinetic model

The Clark kinetic model uses the Freundlich model constant \( n \) to give a procedure for simulating breakthrough curves. The linearized form (Dutta et al., 2012) of the Clark model is expressed as Eq. 18:

\[
\ln\left[\left(\frac{C_o}{C_t}\right)^{n-1} - 1\right] = \ln A - rt \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (18)
\]

where: \( A \) and \( r \) (min\(^{-1}\)) are Clark constants. A plot of \( \ln\left[\left(\frac{C_o}{C_t}\right)^{n-1} - 1\right] \) vs \( t \) gives a straight line with slope equal to \( r \) and intercept equal to \( \ln A \).

3. RESULTS AND DISCUSSION

3. 1. Effect of initial solution concentration

The effect of \( C_o \) on the breakthrough curves at bed height 20cm, flow rate 13.3ml/min and pH 5.32 is shown in Fig.2. It is observed that for all the \( C_o \) values used, before the first 30min, the adsorption had reached over 90% of the \( C_o \) which is near saturation point (Han et al., 2007). However, the \( q_e \) 0.53, 0.73 and 2.82mg/g for \( C_o \) values 10, 50 and 100mg/L respectively show that the \( q_e \) (mg/g) increased with increase in \( C_o \). This result is in agreement with literature (Salman et al., 2011).
The increase in $q_e$ with increase in $C_0$ can be explained by the fact that more adsorption sites were being covered as the $C_0$ increased (Engin, 2009). Experimental data (Table 2) show 100mg/L as the optimum $C_0$.

3. 2. Effect of carbon bed height

The effect of carbon bed height on the adsorption of MY on NaOH-activated carbon from cassava peels at $C_0$ 10 mg/L, pH 5.32 and $Q$ 13.3 ml/min is depicted in Fig. 3. The figures show a breakthrough curve with breakthrough time of 120min and exhaustion time of 360 min for bed height 10 cm.

The $q_e$ values 4.12, 0.53 and 0.21 mg/g for bed heights 10, 20 and 30 cm respectively show that $q_e$ increased with decrease in bed height. This result agrees with literature. This shows that at smaller bed height the effluent adsorbate concentration ratio increased more rapidly than for a higher bed height. Furthermore, the bed is saturated in less time for smaller bed heights. Small bed height corresponds to fewer amounts of adsorbent Nwabanne and Igbokwe, 2012).

3. 3. Effect of flow rate

The effect of flow rate on the adsorption of MY on NaOH-activated carbon from cassava peels at $C_0$ 10 mg/L, bed height 20 cm, and pH 5.32 is shown in Fig. 4. The figure shows a breakthrough curve with breakthrough point at 60 min and saturation point at 330 min. The figure also shows that at higher flow rate, saturation was faster. The $q_e$ values 0.634, 0.518 and 0.428 mg/g for flow rate, 13.3, 25 and 34 ml/min respectively show that $q_e$ increased with decrease in flow rate.

This agrees with the literature (Nidheesh et al., 2012). This is attributed to the fact that as the contact time between the adsorbate and the adsorbent decreased the adsorption efficiency in the carbon bed reduced. At higher flow rate, the movement of adsorption zone along the bed was faster decreasing the time for adsorption of the MY on the carbon bed (Al-Fatlawi and Neamah, 2015).

3. 4. Isotherm modelling

3. 4. 1. Langmuir isotherm model

A plot of $1/q_e$ vs $1/C_e$ gave a straight line (Fig. 5) from which the slope and intercept, $K_L$ and $q_m$ were determined. The values of $K_L$ and $q_m$ are shown in Table 3. The $R^2$ (0.6575) value shows that Langmuir model is a good fit for modelling the adsorption process.

The favourability of the biosorption was confirmed (Bello et al., 2012) by applying the Hall separation factor $R_L$, expressed as Eq. 10. The $R_L$ value (0.172) shows that the process was favourable since $R_L < 1$.

3. 4. 2. Freundlich isotherm model

Fig. 6 shows a plot of $\ln q_e$ vs $\ln C_e$. The values of $K_F$, $1/n$ and $n$ are shown in Table 3. The value of $n$ (1.587), shows that the adsorption was a good, favourable and physisorption process (Al-Fatlawi and Neamah, 2015). The $R^2$ value (0.7116) shows the Freundlich model is a good fit for analyzing experimental data.
3. 4. 3. Temkin isotherm model

A plot of $q_e$ vs $\ln C_e$ gave a straight line (Fig. 7). Table 3 shows the values of $A_T$ and $b_T$. The $R^2$ value (0.6111) shows that the Temkin isotherm is a good fit for analyzing experimental data.

3. 5. Kinetic modelling

3. 5. 1. Application of the Thomas model

Experimental adsorption data were analysed with the Thomas model in order to determine the Thomas parameters shown in Figs. 8-10 and Table 4, for various $C_o$, bed heights and flow rates. The figures and table show that at constant bed height and flow rate, $q_o$ increased with increase in $C_o$ while $K_{TH}$ decreased. The $R^2$ values which are above 0.9 shows that this model is a good fit. All results show that the Thomas model analysed the experimental data well at all $C_o$, bed height and flow rate. The results are in agreement with literature (Nwabanne and Igbokwe, 2012; Baek et al., 2007).

3. 5. 2. Application of Yoon-Nelson kinetic model

Experimental data were analysed with the Yoon-Nelson kinetic model to determine the model parameters $K_{YN}$, $\tau$, $q_o$ and $R^2$ values at various $C_o$, bed heights and flow rates, pH 3 and temperature 29°C. The plots are shown in Figs. 11-13, and values of parameters in Table 5. Results show that $K_{YN}$ and $q_o$ increased with increase in $C_o$; $q_o$ and $\tau$ increased with increase in bed height but the $\tau$ decreased; $q_o$ and $\tau$ values decreased with increase in flow rate. The values of $R^2$ in all the conditions were generally above 0.9 showing that the Yoon-Nelson model simulated experimental data well.

3. 5. 3. Application of Clark kinetic model

A plot of $\ln \left( \left( \frac{C_o}{C_t} \right)^{n-1} - 1 \right)$ vs $t$ gave a straight line (Fig. 14-16). The values of $A$, $n$ and $r$ are shown in Table 6. The $R^2$ (> 0.95) shows that Clark model simulated experimental data well.

3. 6. Spontaneity of the biosorption process

The spontaneity of the process was determined (Depci et al., 2012) by applying Eq. 19:

$$\Delta G_{ads}^o = RT \ln K_D$$  \hspace{1cm} (19)

where: $\Delta G_{ads}^o$ is the standard free energy of biosorption, $R$ (8.314 J/mol/K) is the gas constant, $T$ (K) is the absolute temperature and $K_D$ is the equilibrium distribution constant. $K_D$ is determined (Salman et al., 2011) from Eq. 20:

$$K_D = \frac{(C_o - C_e)e}{C_e}$$  \hspace{1cm} (20)
The $K_D$ values for $C_0$ 10, 50 and 100 mg/L were determined as 0.034, 0.009 and 0.017 respectively. The $\Delta G_{ads}$ values were calculated to be -8.49, -11.827 and -10.23 kJ/mol for $C_0$ 10, 50 and 100 mg/L respectively. The magnitudes of these values and their negative values show that the process was spontaneous for all $C_0$ values. The Freundlich constant $n$ value (1.587) shows that the adsorption was good and physical (Al-Fatlawi and Neamah, 2015).

4. CONCLUSION

Sodium hydroxide-activated carbon prepared from cassava peels waste was used to remove MY from aqueous solution in a fixed-bed column. Effects of $C_0$, bed height and flow rate were studied after adsorption times of 480 min for various $C_0$ and bed heights, and 360 min for flow rate. $q_e$ increased with increase in $C_0$ and decrease in flow rate. However, $q_e$ increased with decrease in carbon bed height. The highest $q_e$ of 4.12 mg/g was obtained with $C_0$ 10 mg/L, bed height 10 cm and bed height 13.3 ml/min. Langmuir, Freundlich and Temkin isotherm, as well as Thomas, Yoon-Nelson and Clark kinetic models simulated experimental data well as shown by the $R^2$. The results show very low efficiency in the removal of MY from aqueous solution by NaOH-activated carbon from cassava peels.

References


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Table 1. Physicochemical properties of NaOH-activated carbon from cassava peels

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
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<td>pH</td>
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<tr>
<td>Specific surface area (m²/g)</td>
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<tr>
<td>Pore volume (cm³/g)</td>
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<td>Porosity</td>
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<td>Bulk density (g/cm³)</td>
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<td>Fixed carbon content(%)</td>
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<td>Ash content(%)</td>
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Table 2. Column data parameters obtained at different initial dye concentrations, bed heights and flow rates

<table>
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<tr>
<th>Initial Concentration (mg/L)</th>
<th>Carbon bed height (cm)</th>
<th>flow rate (ml/min)</th>
<th>q_{tot} (mg/g)</th>
<th>q_e (mg/g)</th>
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</table>

Table 3. Thomas kinetic model parameters at different conditions using linear regression analysis.

<table>
<thead>
<tr>
<th>Initial Conc. (mg/L)</th>
<th>Carbon bed height (cm)</th>
<th>Flow rate (ml/min)</th>
<th>K_{Th} ×(10^{-4}) (ml/min.mg)</th>
<th>q_o (mg/g)</th>
<th>R^2</th>
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<td>10</td>
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<td>34</td>
<td>3.1</td>
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</table>
Table 4. Yoon-Nelson kinetic model parameters at different conditions using linear regression analysis

<table>
<thead>
<tr>
<th>Initial Conc. (mg/L)</th>
<th>Carbon bed height (cm)</th>
<th>flow rate (ml/min)</th>
<th>$K_{YN} \times (10^{-3})$</th>
<th>$\tau$ (min)</th>
<th>$q_0$ (mg/g)</th>
<th>$R^2$</th>
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</thead>
<tbody>
<tr>
<td>10</td>
<td>20</td>
<td>13.3</td>
<td>1.9</td>
<td>1223.16</td>
<td>40.67</td>
<td>0.951</td>
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<td>50</td>
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<td>5.3</td>
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</table>

Table 5. Clark kinetic model parameters at different conditions using linear regression analysis.

<table>
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<tr>
<th>Initial Conc. (mg/L)</th>
<th>Carbon bed height (cm)</th>
<th>flow rate (ml/min)</th>
<th>$r$</th>
<th>$A$</th>
<th>$R^2$</th>
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<tbody>
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<td>20</td>
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<tr>
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<td>13.3</td>
<td>0.0008</td>
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<tr>
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Table 6. Isotherm parameter data for fixed-bed biosorption of my on naoh-activated carbon.

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameter</th>
<th>Value</th>
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</thead>
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<td>Langmuir</td>
<td>$K_L$ (L/mg)</td>
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<tr>
<td></td>
<td>$q_m$ (mg/g)</td>
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<tr>
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<td>$R_L$</td>
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<td>$R^2$</td>
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<tr>
<td>Freundlich</td>
<td>$1/n$</td>
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<tr>
<td></td>
<td>$n$</td>
<td>1.587</td>
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<tr>
<td></td>
<td>$K_F [mg/g(L/mg)^{1/n}]$</td>
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<tr>
<td></td>
<td>$R^2$</td>
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<tr>
<td>Temkin</td>
<td>$A_T$ (L/g)</td>
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<tr>
<td></td>
<td>$b_T$ (J/mol)</td>
<td>3014.561</td>
</tr>
<tr>
<td></td>
<td>$R^2$</td>
<td>0.6111</td>
</tr>
</tbody>
</table>

Fig 1. Structure of metanil yellow
Fig. 2. Adsorption of MY on NaOH-activated carbon at various $C_0$.

Fig. 3. Adsorption MY on NaOH-activated carbon at various bed heights.
**Fig. 4.** Adsorption of MY on NaOH-activated carbon at various flow rates

**Fig. 5.** Langmuir Type 2 isotherm model plot for adsorption of MY on NaOH-activated carbon
Fig. 6. Freundlich isotherm model plot for adsorption of MY on NaOH-activated carbon

\[ y = 0.6303x - 2.2306 \]
\[ R^2 = 0.7116 \]

Fig. 7. Temkin isotherm model plot for adsorption of MY on NaOH-activated carbon

\[ y = 0.8329x - 1.6284 \]
\[ R^2 = 0.6111 \]
Fig. 8. Thomas plot model for the adsorption of MY on NaOH-activated carbon at various $C_o$.

$$y = -0.0019x - 2.3187$$
$$R^2 = 0.9517$$

$$y = -0.0027x - 3.2546$$
$$R^2 = 0.9297$$

$$y = -0.001x - 3.5507$$
$$R^2 = 0.8019$$

Fig. 9. Thomas model plot for the adsorption of MY on NaOH-activated carbon at various bed heights.

$$y = -0.0052x + 0.2328$$
$$R^2 = 0.9443$$

$$y = -0.0019x - 2.3187$$
$$R^2 = 0.9516$$

$$y = -0.0016x - 3.0225$$
$$R^2 = 0.8824$$
**Fig. 10.** Thomas model plot for the adsorption of MY on NaOH-activated carbon from at various flow rates

**Fig. 11.** Yoon-Nelson model plot for the adsorption of MY on NaOH-activated carbon at various $C_0$
**Fig. 12.** Yoon-Nelson model plot for the adsorption of MY on NaOH-activated carbon at various bed heights.

**Fig. 13.** Yoon-Nelson model plot for the adsorption of MY on NaOH-activated carbon at various flow rates.
Fig. 14. Clark kinetic model plots for adsorption of MY on NaOH-activated carbon at various $C_0$.

Fig. 15. Clark kinetic model plots for adsorption of MY on NaOH-activated carbon at various bed heights.
Fig. 16. Clark kinetic model plots for adsorption of MY on NaOH-activated carbon at various flow rates