

# Methylene Blue Adsorption onto Coconut husks/Poly lactide Blended Films: Equilibrium and Kinetic Studies

Ali Shee<sup>1\*</sup>, John Mmari Onyari<sup>2</sup>, John Namakwa Wabomba<sup>2</sup>, Daniel Munga<sup>1</sup>

1. Department of Pure and Applied Sciences, Technical University of Mombasa, P.o Box 90420-80100, Mombasa-Kenya.

2. Department of Chemistry, University of Nairobi, P.o Box 30197-00100, Nairobi-Kenya

\*sheeali01@gmail.com

## Abstract

The removal of cationic methylene blue (MB) from aqueous solutions by coconut husks/poly lactide blended films was studied in a batch system. Experiments were modeled as a function of contact time, initial dye concentration, ionic strength, adsorbent dose, temperature and initial solution  $p^H$ . Equilibrium data fitted the Langmuir isotherm model ( $R^2 > 0.9866$ ) with monolayer adsorption capacity  $q_m = 16.34 \text{ mg/g}$  at 296K. Adsorption kinetics followed the pseudo-second model ( $R^2 > 0.9997$ ) hence chemisorption rate limiting step was dominant. The results have shown viability of coconut husks/poly lactide blended films for the removal of recalcitrant MB from both domestic and industrial wastewaters.

**Key words:** coconut husks, poly lactide, methylene blue, isotherm, kinetics

## 1. Introduction

Increased global growth of textile industries has led to high volumes of dye laden wastewaters [1-3]. The annual global consumption of synthetic dyes by textile industries is in excess of  $1.0 \times 10^7$  kilograms [4] with almost 1 million kilograms discharged into the aqueous environment [5]. Most synthetic dyes are aromatic in nature making them physical, chemical, thermal, biological and optical stable. Upon degradation, the dye products are toxic, carcinogenic and mutagenic to life forms [6, 7].

Methylene blue is a heterocyclic aromatic cationic dye widely used in the dyeing of paper, linen, textiles, bamboo and wood. It's stable and resistant to chemicals, physical stressors, and microorganisms. Exposure to MB causes increased heartbeat, shock, vomiting, cyanosis, jaundice, quadriplegia and tissue necrosis [8]. Hence, the removal of MB dye from textile wastewater is essential to protect the health of both aquatic and terrestrial ecosystems.

A variety of physical, chemical and biological treatment methods have been reported [9-11]. The choice of method is limited by cost, efficiency, release of secondary effluents and simplicity in design for operation [12-14]. Among the treatment methods, adsorption of dye molecules onto adsorbents such as biomass, clays and algae is the most preferred. It is simple, efficient and cost effective [10-12].

Recently, blending biopolymers with agricultural wastes has led to adsorbents with improved efficiency. Poly lactide/spent brewery grains (SBGs) films have been applied to remove malachite green [15]. Blends of polyvinyl alcohol (PVA) with scleroglucan, cellulose microfibers and zein and Chitosan-g-poly (acrylic acid)/vermiculite hydrogel composites have shown potential for MB dye removal [16, 17]. In the present study coconut husks/poly lactide blended films prepared by solvent-casting method using dichloromethane have been investigated for methylene blue adsorption.

Poly lactide (PLA) is biodegradable aliphatic polyester with high strength, modulus thermoplastic and easily processed [18, 19]. Decreased production cost has diversified its application from biomedical to packaging, textile fibers and composite materials [20, 21]. Blending of PLA with other biopolymers has been found to enhance its properties [15, 22]. Coconut husks are agricultural wastes obtained from coconut trees that grow in low altitude areas along warm coastlines.

## 2. Experimental Methods

### 2.1 Materials

Coconut husks were collected from Vuga in Kwale County, Kenya. They were ground into fine powder and washed with warm water until clean. Clean powder was soaked in distilled water, washed thoroughly and dried to constant weight in a thermostat oven at 313K for 8 hours. Dry powder was sieved into  $< 300 \mu\text{m}$  particle size

and used in subsequent studies with polylactide (PLA). Equal masses of PLA and coconut husks powder were uniformly mixed in liquid dichloromethane. The mixture was then spread onto a thin film on a glass plate and dried at 313K in an oven for 8 hours. Dry films were removed and stored. Plain PLA films were prepared in dichloromethane as control.

Cationic methylene blue was purchased from Kobian Scientific-Kenya (Merck Manufacturers) and used without further purification. Experimental dye solutions were prepared from 1000mg/L MB stock solution.

## 2.2 Batch Adsorption Experiments

Experiments were carried out in triplicate at 296K by agitating a fixed mass of adsorbent with 50mL MB of known initial concentration and neutral pH in 250ml Erlenmeyer flasks on an orbital shaker preset at 300rpm. Effect of contact time on adsorption was studied using 0.125g of CH-PLA blended films with 26mg/L MB concentration and measuring residual dye concentration every 5 minutes at  $\lambda_{\max} = 645\text{nm}$  using a UV/VIS spectrophotometer (Turner Model SP-850) for 120 minutes. The same procedure was repeated with Plain PLA films as control.

Effect of initial dye concentration on adsorption was studied using 50mL dye of initial concentration varied from 20mg/L to 32mg/L in conjunction with 0.125g adsorbent and all other experimental conditions kept constant. Adsorbent dosage was increased from 0.1g to 0.175g. Initial MB pH was adjusted from 1.5 to 12.5 using 0.05M  $\text{HCl}_{(\text{aq})}$ , 0.05M  $\text{NaOH}_{(\text{aq})}$  and distilled water.

Effect of temperature on adsorption was studied using 40ml of 26mg/L MB solutions and 0.125g CH-PLA blended films. Temperature was varied from 293K to 323K using metabolic shaking incubator (Dubnoff) preset at 400rpm and 25 minutes equilibration time.

Effect of salts on adsorption was studied using 25ml of 26mg/L initial MB concentrations added to seven 250ml Erlenmeyer flasks. To each of the flask, varying amounts 0.1M  $\text{NaCl}_{(\text{aq})}$  and distilled water were added followed by 0.125g of CH-PLA blended films and agitated at 300rpm on an orbital shaker for 40 minutes equilibration time.

## 2.3 Adsorption Isotherms

Adsorption isotherms were done at 296K where 50mL of MB solutions of different initial concentrations (20-32mg/L) were placed in a set of 250ml Erlenmeyer. About 0.125g of adsorbent was added to each flask containing dye solution and agitated at 300rpm on an orbital shaker for 60 minutes equilibration time. Residual dye concentration at equilibrium was measured at  $\lambda_{\max} = 645\text{nm}$  using a UV/VIS spectrophotometer (Turner Model SP-850). The equilibrium adsorption capacity,  $q_e$  (mg/g) for the adsorbent was calculated using equation 1:

$$q_e = \frac{C_0 - C_e}{M} \times V \quad (1)$$

Where  $C_0$  and  $C_e$  are the initial and residual MB concentrations (mg/L) respectively while  $M$  is adsorbent weight (g) and  $V$  is the volume of solution (L).

## 3. Results and Discussions

### 3.1 Effects of Contact Time

The influence of contact time on MB adsorption is shown in figure 1. Dye uptake was rapid within initial 5 minutes due to higher number vacant adsorption sites on adsorbent surface [15, 23]. Adsorption equilibrium time was 60 minutes for CH-PLA blended films and 10 minutes for Plain PLA films. At equilibrium, the rate of dye adsorbing and desorbing from the adsorbent surface is almost constant. Hence any increase in contact time has less influence on adsorption. The amount of dye adsorbed at the equilibrium time reflects the maximum adsorption capacity of the specific adsorbent,  $q_e$  (mg/g), under the given operating conditions [24]. Similar observations have been reported by Abdallah and Taha, [25] on *Aspergillus fumigates*. Equilibrium adsorption capacity  $q_e$ , for CH-PLA blended films and plain PLA films were 9.74mg/g and 1.72mg/g respectively. Plain PLA films have lower uptake of cationic MB dye molecules compared to the blended films. Chanzu *et al.*, [15] also demonstrated lower removal of cationic malachite green dye onto Plain PLA films compared to PLA/SBGs blended films. Hence this indicates that Plain PLA has low affinity for cationic dyes.

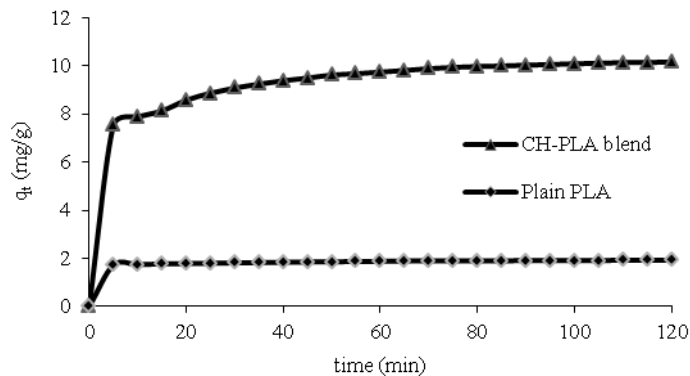


Fig 1: Effect of contact time for methylene blue adsorption

### 3.2 Effect of Initial Methylene Blue Concentration

The effect of initial MB dye concentration on adsorption was investigated and the results shown in figure 2. MB uptake increased with increasing initial dye concentration. At lower MB concentration, fractional adsorption (the ratio between the numbers of dye molecules to the number of available actives sites) is low and adsorption is independent of initial dye concentration. On the other hand the number of dye molecules is higher when concentration is increased resulting to a higher fractional adsorption hence increased uptake. Generally, it is believed that a higher initial dye concentration provides greater driving force to overcome mass transfer resistance between the aqueous and solid surfaces hence enhancing sorption process [24].

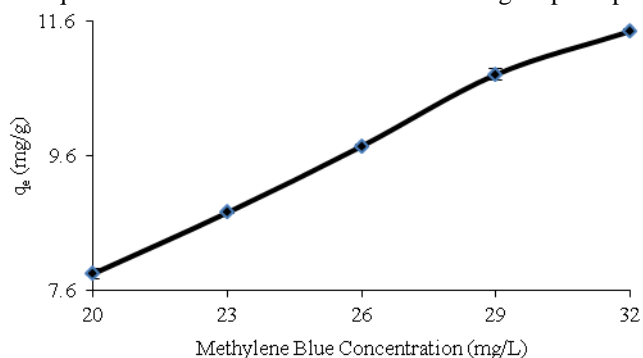


Fig 2: Effect of initial methylene blue concentration on adsorption

### 3.3 Effect of Initial Adsorbent Dose

Effect of adsorbent dose on adsorption was investigated using fixed initial MB concentration at 26mg/L while varying adsorbent dose from 0.1g to 0.175g. As shown in figure 3, equilibrium adsorption capacity,  $q_e$  (mg/g) decreases with an increase in adsorbent dose. At low adsorbent dose, surface active sites are readily accessible by dye molecules hence higher adsorption capacity. On the hand an increase in adsorbent dose increases number of surface active sites. However, overlapping of adsorbent particles hinders dye molecules access to surface active sites hence lower adsorption. Thus low adsorbent dose increases adsorption capacity [24].

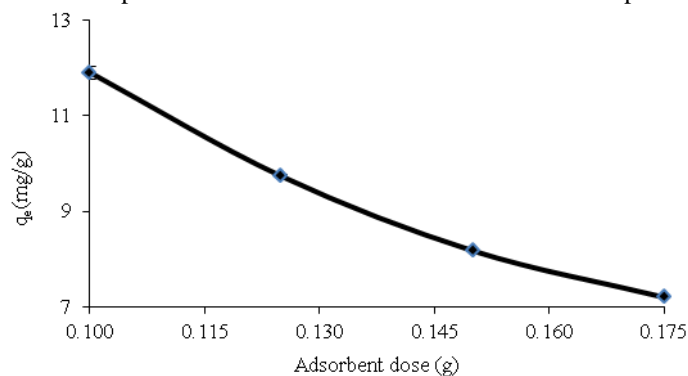


Fig 3: Effect of initial adsorbent dose on adsorption

### 3.4 Effect of Ionic Strength

Wastewaters especially from textile industries contain varying quantities of metal ions which significantly affect the adsorption process. In this study, volumes of distilled water and 0.1M NaCl<sub>(aq)</sub> were varied to alter the concentration of Na<sup>+</sup><sub>(aq)</sub> and Cl<sup>-</sup><sub>(aq)</sub> ions in solution. These ions interact with dissociated dye molecules and compete to adsorb on adsorbent surfaces. About 25ml of 26mg/L initial MB at neutral p<sup>H</sup> was used and all other experimental conditions kept constant. After equilibrium was attained, adsorption capacity of adsorbent was evaluated. Figure 4 shows that increased ionic strength lowers adsorption of MB. The decrease could be attributed to competition for available active sites between the cationic dye molecules and the positively charged Na<sup>+</sup><sub>(aq)</sub> being introduced [26]. A higher concentration of Na<sup>+</sup><sub>(aq)</sub> outnumber cationic dye molecules leading to decreased adsorption. Further smaller Na<sup>+</sup><sub>(aq)</sub> ions easily access anionic sites on adsorbent surface compared to the larger cationic dye molecules. It's also believed increased salt concentration expands the thickness of the electrical diffused double layer between adsorbate species and adsorbent surface. This expansion decreases electrostatic attraction of dye molecules to adsorbent surface hence low adsorption [15].

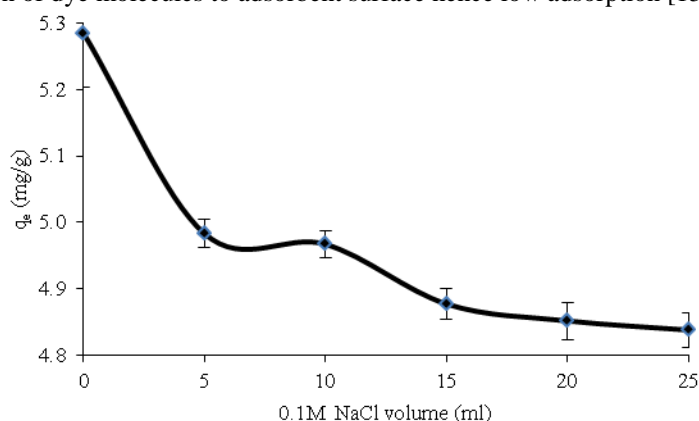


Fig 4: Effect of ionic strength on adsorption

### 3.5 Effect of Initial Methylene Blue p<sup>H</sup>

Adsorption is normally p<sup>H</sup> dependent. Initial p<sup>H</sup> affects dye stability as well as surface characteristics of adsorbents [9, 15, 27]. The adsorption process was investigated over p<sup>H</sup> range from 1.5 to 12.5. Figure 5 shows that an increase in p<sup>H</sup> to 3.0 increases MB adsorption. This could be attributed to buildup of negative charge on the adsorbent surface which strongly attracts the cationic dye. At lower p<sup>H</sup>, H<sup>+</sup><sub>(aq)</sub> compete with MB molecules for adsorption onto adsorbent anionic sites hence lower MB adsorption. However as p<sup>H</sup> is increased from 3.0 to 12.5 there is a reduction in MB removal. The secondary formation of NaCl<sub>(aq)</sub> due to displacement of Cl<sup>-</sup><sub>(aq)</sub> from MB molecule with NaOH<sub>(aq)</sub> decreases dye adsorption. Increasing amounts of NaCl<sub>(aq)</sub> therefore increases small Na<sup>+</sup><sub>(aq)</sub> ions that compete with the cationic dye molecules for anionic sites on the adsorbent [28].

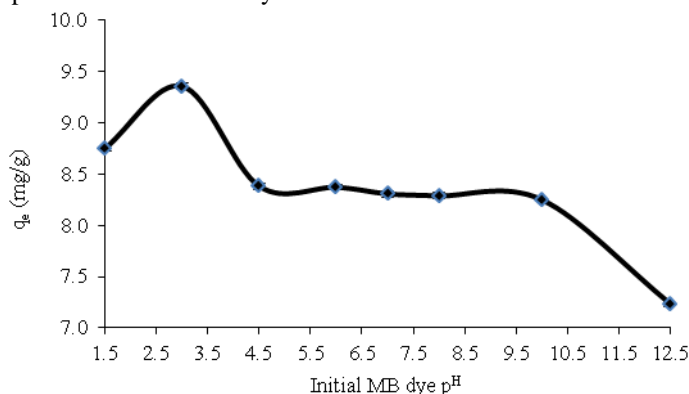
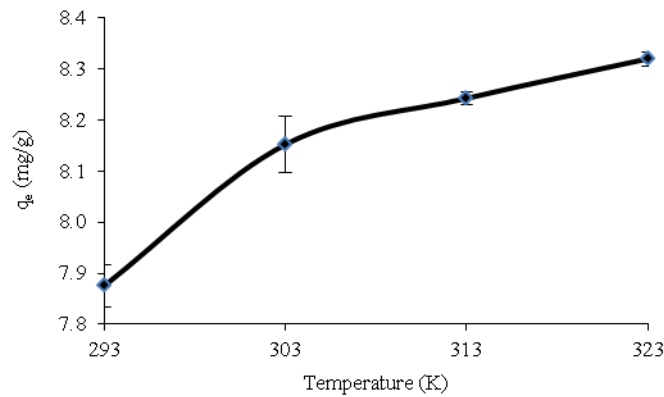


Fig 5: Effect of initial solution pH on adsorption

### 3.6 Effect of Temperature

Temperature has been found to alter the rate of dye molecules, viscosity of solution media and surface characteristics of adsorbent. The effect of temperature on the adsorption of MB onto CH-PLA was investigated within temperature range of 293-323K and the results shown in figure 6. The adsorption process was

endothermic. An increase in temperature reduces viscosity of solution and causes activation of adsorbent surfaces which enhances the rate of diffusion of adsorbate molecules across the external boundary layer as well as in the internal pores of particles [29]. The endothermic nature on the adsorption of MB by adsorbents has also been reported by Sajab *et al.*, [30] on oil palm empty fruit bunch fibers.



**Fig 6:** Effect of temperature on adsorption

### 3.7 Adsorption Isotherms

Isotherm models are used to describe the relationship between amounts of adsorbed dye with its equilibrium concentrations in solution. The Langmuir isotherm (equation 2) is based on the theoretical principle that only a monolayer exists on an adsorbent. Its linear form is written as [31]:

$$\frac{C_e}{q_e} = \frac{1}{q_m K_L} + \frac{C_e}{q_m} \quad (2)$$

Main features of equation 2 are described by the dimensionless separation factor  $R_L$  given as:

$$R_L = \frac{1}{q_m K_L} \quad (3)$$

Where  $C_e$ ,  $q_e$ ,  $q_m$  and  $K_L$  respectively are equilibrium dye concentration (mg/L), equilibrium adsorption capacity (mg/g), Langmuir monolayer constant (mg/g) and Langmuir constant for adsorption energy (L/mg). The shape of the isotherm can be described as unfavorable ( $R_L > 1$ ), linear ( $R_L = 1$ ), favorable ( $0 < R_L < 1$ ) and irreversible ( $R_L = 0$ ) [32]. A plot of  $\frac{C_e}{q_e}$  against  $C_e$  is linear for a sorption process obeying the basis of this equation with  $q_m$  and  $K_L$  obtained from the slope and intercept respectively.

The Freundlich Isotherm assumes that dye uptake occurs on a heterogeneous surface by multilayer adsorption and amount of adsorbed adsorbate increases infinitely with an increase in concentration. The linear form of the Freundlich isotherm is presented in equation 4 [33]:

$$\log_{10} q_e = \log_{10} K_F + \frac{1}{n} \log_{10} C_e \quad (4)$$

Where  $n$  and  $K_F$  are number of layers and Freundlich constant respectively. For a sorption process obeying this model, the plot of  $\log_{10} q_e$  against  $\log_{10} C_e$  is linear with  $K_F$  and  $n$  obtained from the intercept and slope respectively. Values of  $n$  between 1 and 10 indicate a favorable adsorption process [34] while higher  $K_F$  values indicate an easy uptake of dye from solution [35].

The isotherm parameters with regression coefficients presented in table 1 were obtained from linear plots of Langmuir isotherm (figure 7) and Freundlich isotherm (figure 8). The experimental data fits well to Langmuir isotherm model ( $R^2 > 0.9866$ ) compared to Freundlich isotherm model ( $R^2 > 0.9722$ ). Therefore adsorption process was favorable ( $R_L = 0.0805$ ) and occurs through a monolayer formation ( $q_m = 16.34 \text{ mg/g}$ ) on the adsorbent.

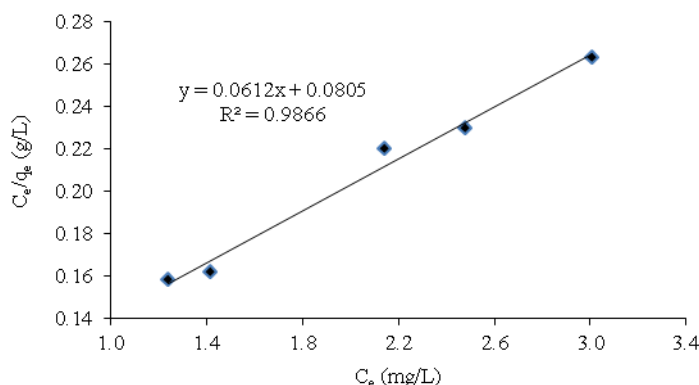


Fig 7: Langmuir isotherm plot

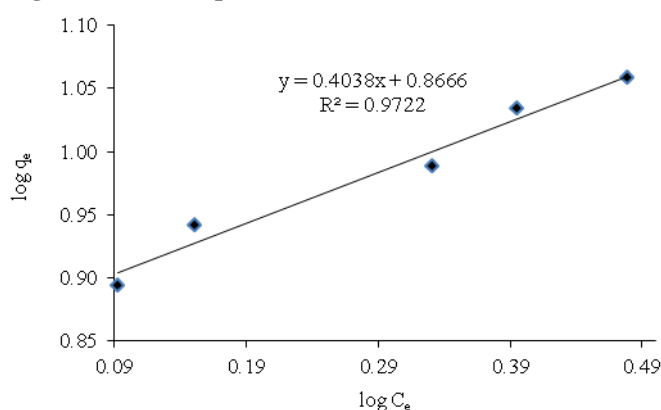


Fig 8: Freundlich isotherm plot

Table 1: Langmuir and Freundlich Isotherm Parameters

Langmuir Isotherm				Freundlich Isotherm		
$q_m$ (mg/g)	$K_L$ (L/mg)	$R^2$	$R_L$	$K_F$ (mg/g)	$n$ (g/l)	$R^2$
16.34	0.7602	0.9866	0.0805	7.36	2.4765	0.9722

### 3.8 Adsorption Kinetics

To describe the adsorption mechanism experimental data was fitted to kinetic models. Adsorption kinetics was investigated using pseudo-first-order kinetics, pseudo-second-order kinetics and intra-particle diffusion models. The Lagergren [36] pseudo-first order kinetics model is presented in equation 5 as:

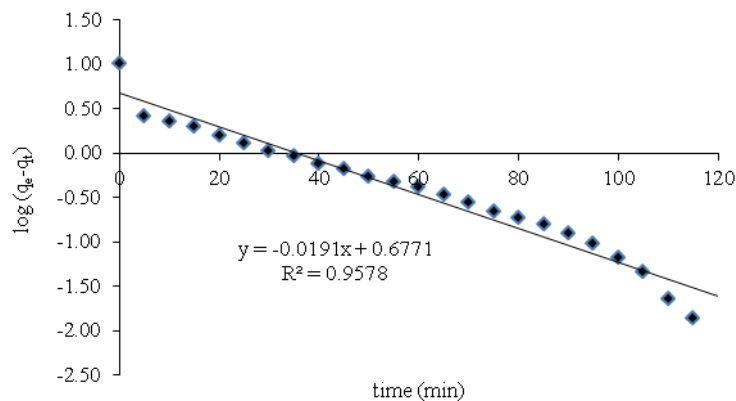
$$\log (q_e - q_t) = \log q_e + \frac{K_1}{2.303}t \quad (5)$$

Where  $q_t$ ,  $K_1$  and  $t$  are adsorption capacity at a given time (mg/g), pseudo-first order adsorption rate constant ( $\text{min}^{-1}$ ) and time (min) respectively. A linear plot of  $\log (q_e - q_t)$  against  $t$ , gives  $q_e$  (mg/g) as intercept and  $K_1$  from slope.

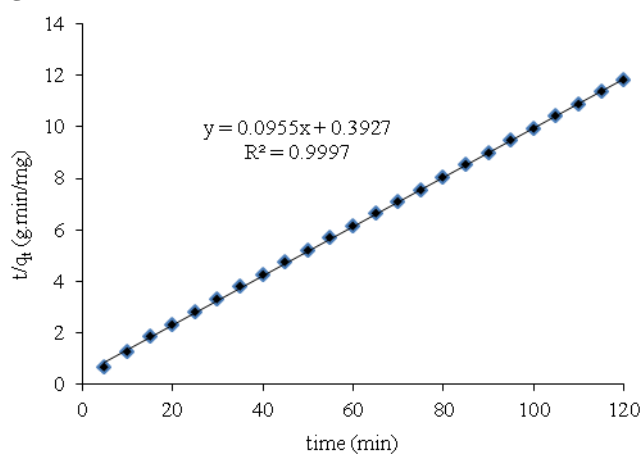
The linear form of the Lagergren pseudo-second order kinetics model described by Ho and McKay [37] is given in equation 6 as:

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{t}{q_e} \quad (6)$$

Where  $K_2$  is the pseudo-second order adsorption rate constant ( $\text{gmin}^{-1}\text{mg}^{-1}$ ). The linear plot of  $\frac{t}{q_t}$  against  $t$ , enables calculation of  $q_e$  (mg/g) from the slope and intercept  $K_2$ . The kinetic parameters for the linear plots of pseudo-first-order (figure 9) and pseudo-second-order (figure 10) are shown in table 2. The adsorption of MB onto coconut husks/polylactide films follows pseudo-second-order kinetics since  $q_{e,\text{exp}}$  are in agreement with  $q_{e,\text{cal}}$  (table 2) and higher correlation coefficient ( $R^2 > 0.9997$ ). Hence the adsorption of MB through pseudo-second order kinetics implies that the rate limiting step during adsorption is based on chemisorption. Therefore the adsorption rate was dependent on both concentration of dye molecules and surface characteristics of the adsorbent.



**Fig 9: Pseudo-first order kinetics model**



**Fig 10: Pseudo-second order kinetics model**

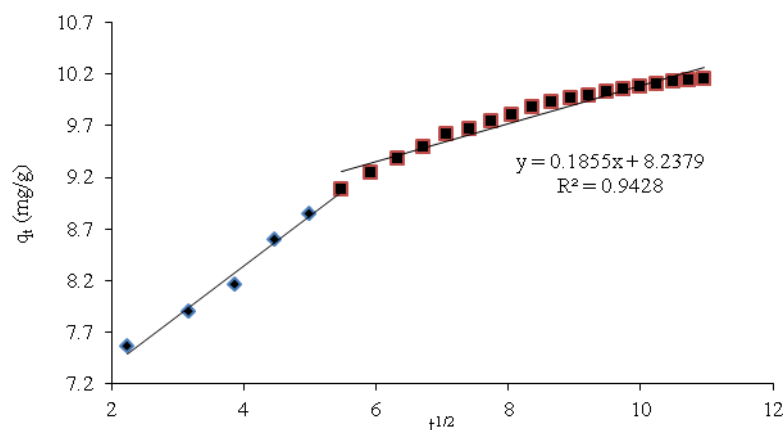
**Table 2: Kinetic Parameters for Adsorption of MB dye onto Coconut Husks/Polylactide Films**

Pseudo-first order				Pseudo-second order			Intra-particle Diffusion		
$q_{e,exp}$ (mg/g)	$q_{e,cal.}$ (mg/g)	$K_1$ (min <sup>-1</sup> )	$R^2$	$q_{e,cal.}$ (mg/g)	$K_2$ (gmin <sup>-1</sup> mg <sup>-1</sup> )	$R^2$	$K_{diff.}$ (mg/g)	$C$ (mg/g)	$R^2$
10.15	4.75	0.044	0.9578	10.47	0.0232	0.9997	0.1855	8.24	0.9428

According to Weber and Morris [38], intra-particle diffusion processes are normally expressed in terms of the square root of time. The intra-particle diffusion process model is given in equation 7 as:

$$q_t = K_{diff.} t^{1/2} + C \quad (7)$$

Where  $K_{diff.}$  is intra-particle diffusion rate constant (mgg<sup>-1</sup>min<sup>-1/2</sup>) and  $C$  represents boundary layer thickness. Intra-particle diffusion is normally a slow process preceded by mass transport of adsorbate molecules to adsorbent surface. Mass transport resistance could be eliminated for a well agitated system. If intra-particle diffusion is rate controlling then the plot of  $q_t$  against  $t^{1/2}$  is linear with slope giving  $K_{diff.}$  and  $C$  from intercept. If  $C$  is close to zero then diffusion is the only rate limiting step [39]. Higher  $C$  values indicate greater contribution of surface sorption in rate determining step. Figure 11 gives the intra-particle diffusion plot for MB adsorption onto coconut husks/polylactide blended films.



**Fig 11: Intra-particle diffusion model**

Two steps characterize the adsorption process. The first initial rapid step is correlated with the boundary layer diffusion of adsorbate. This is followed by a gradual adsorption of MB molecules where intra-particle diffusion is rate controlling. The linear curves do not pass through the origin hence intra-particle diffusion is not the only rate controlling step. Therefore more than one process affects adsorption process [40-42].

The intra-particle diffusion parameters obtained in the second step adsorption process presented in table 2 shows that the boundary layer thickness  $C$  is 8.24mg/g indicating greater contributions of surface sorption in the rate controlling step. Therefore, the adsorption of MB is a multi-step process involving adsorption on the external surface and diffusion into the interior [43].

#### 4. Conclusions

The adsorption of methylene blue was influenced by several operational factors such as contact time, temperature and solution  $p^H$ . Adsorbent adsorption capacity at equilibrium increased with increase in temperature, initial dye concentration and contact time. However increased adsorbent dosage and ionic strength lowers adsorption capacity of adsorbent. Maximum adsorption was found at  $p^H < 3$  and decreased at higher  $p^H$ . The experimental data agrees well with the Langmuir model ( $R^2 > 0.9866$ ). On the basis of the Langmuir model, the monolayer adsorption capacity for the adsorbent,  $q_m$  is 16.34mg/g at 296K. The adsorption process follows pseudo-second kinetics model ( $R^2 > 0.9997$ ) hence chemisorption. Thus adsorption of MB onto coconut husks/polylactide blended films is influenced both by number of surface active sites on adsorbent as well as dye concentration.

The plot of adsorption capacity,  $q_t$  (mg/g) against  $t^{1/2}$  for intra-particle diffusion depicts a multi-linearity process. Therefore, intra-particle diffusion was not the only rate controlling step and adsorption process is multi-step involving adsorption on the external surface and diffusion into the interior.

#### 5. Acknowledgements

The author greatly appreciates financial support from World Federation of Scientists through the International Centre for insect Physiology and Ecology (ICIPE).

#### 6. References

1. Kadam, A. A., Lade, H. S., Patil, S. M., Govindwar, S. P. (2013). Low cost  $CaCl_2$  pretreatment of sugarcane bagasse for enhancement of textile dyes adsorption and subsequent biodegradation of adsorbed dye under solid state fermentation. *Bioresource Technology* 132: 276-284.
2. Pavan, F. A., Camacho, E.S., Lima, E. C., Dotto, G. L., Branco, V. T. A., Dias, S. L. P. (2014). Formosa papaya seed powder (FPSP): Preparation, characterization and application as an alternative adsorbent for the removal of crystal violet from aqueous phase. *Journal of Environmental Chemical Engineering* 2: 230-238.
3. Yusuff, R.O., Sonibare, J.A. (2004). Characterization of Textile Industries' Effluents in Kaduna, Nigeria and Pollution Implications. *Global Nests: the Int. J.* 6 (3): 212-221.
4. Ahmad, R., Kumar, R. (2010). Adsorptive Removal of Congo red dye by bael shell carbon. *Applied Surface Science* 257: 1628.



5. Cestari, A. R., Vieira, F. S., Vieira, G. S., Almeida, L. E. (2007). Aggregation and adsorption of reactive dyes in the presence of anionic surfactant on mesoporous aminopropyl silica. *Journal of Colloid Interface Science* 309: 402.
6. Suteu, D. Zaharia, C., Muresan, A., Muresan, R., Popescu, A. (2009). Using of industrial waste materials for textile wastewater treatment. *Journal of Environmental Engineering and Management* 8 (5): 1097-1102.
7. Zaharia, C., Suteu, D., Muresan, A., Muresan, R., Popescu, A. (2009). Textile wastewater solutions. *Journal of Hazardous Materials* 167 (1-3): 1-9.
8. Vadivelan, V., Kumar, K. V. (2005). Equilibrium, kinetics, mechanism, and process design for the sorption of Methylene blue onto rice husk. *Journal of Colloid and Interface Science* 286: 90-100.
9. Nguyen, T.H., Juang, R.S. (2013). Treatment of waters and wastewaters containing sulfur dyes: A review. *Chemical Engineering Journal* 219: 109-117.
10. Salleh, M. A. M., Mahmoud, D.K., Abdul Karim, W. A.W., Idris, A. (2011). Cationic and anionic dye adsorption by agricultural solid wastes: A comprehensive review. *Desalination* 280: 1-13.
11. Gupta, V. K., Suhas. (2009). Application of low cost adsorbents for dye removal- a review. *Journal of Environmental Management* 90: 2313-2342.
12. Sulak, M.T., Demirbas, E., Kobya, M. (2007). Removal of Astrazon Yellow 7GL from aqueous solutions by adsorption onto wheat bran. *Bioresource Technology* 98: 2590-2598.
13. Lee, J.W., Choi, S.P., Thiruvengkatchari, R., Shim, W.G., Moon, H. (2006). Evaluation of the performance of adsorption and coagulation processes for the maximum removal of reactive dyes. *Dyes Pigments* 69: 196-203.
14. Indra, D.M., Vimal, C.S., Nitin, K.A., Indra, M.M. (2005). Adsorptive removal of malachite green dye from aqueous solution by bagasse fly ash and activated carbon-kinetic study and equilibrium isotherm analyses. *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 264 (1-3): 17-28.
15. Chanzu, H. A., Onyari, J. M., Shiundu, P.M. (2012). Biosorption of Malachite Green from Aqueous Solutions onto Polylactide/Spent Brewery Grain Films: Kinetic and Equilibrium Studies. *Journal of Polymers and the Environment* 20(3): 665-672.
16. Dobritoiu, R., Patachia, S. (2013). A study of dyes sorption on biobased cryogels. *Applied Surface Science* 285P : 56-64.
17. Liu, Y. Zheng, Y., Wang, A. (2010). Enhanced adsorption of Methylene blue from aqueous solution by chitosan-g-poly(acrylic acid)/vermiculite hydrogel composites. *Journal of Environmental Sciences* 22: 486-493.
18. Liang, HE., Shufen, Z., Bingtao, T., Lili, W., Jinzong, Y. (2009). Dyeability of Polylactide Fabric with Hydrophobic Anthraquinone dyes. *Chinese Journal of Chemical Engineering* 17 (1): 156-159.
19. Gupta, A.P., Kumar, V. (2007). New emerging trends in synthetic biodegradable polymers-Polylactide: A critique. *European Polymer Journal* 43: 4053-4074.
20. Onyari, J.M., Mulaa, F., Muia, J., Shiundu, P. (2008). Biodegradability of Polylactic acid, Preparation and Characterization of PLA/Gum Arabic Blends. *Journal of Polymers and Environment* 16 (3): 205-212.
21. Rhim, J-W., Mohanty, A.K., Singh, S.P., Ng P.K.W. (2006). Effects of the Processing methods on the performance of polylactide films: thermocompression versus solvent casting. *Journal of Applied Polymer Science* 101: 3736-3742.
22. Nampoothiri, K.M., Nair, N.R., John, R.P. (2010). An overview of the recent developments in Polylactide (PLA) research. *Bioresource Technology* 101: 8493-8501.
23. Nasuha, N., Hameed, B. H., Mohd Din, A.T. (2010). Rejected tea as a potential low cost-adsorbent for the removal of Methylene blue. *Journal of Hazardous Materials* 175: 126-132.
24. Patil, S., Deshmukh, V., Renukdas, S., Patel, N. (2011). Kinetics of adsorption of crystal violet from aqueous solution using different natural materials. *International Journal of Environmental Sciences* 1 (6).
25. Abdallah, R., Taha, S. (2012). Biosorption of Methylene blue from aqueous solution by nonviable *Aspergillus fumigates*. *Chemical Engineering Journal* 195-196: 69-76.
26. Han, X., Wang, W., Ma, X. (2011). Adsorption characteristics of Methylene blue onto low cost biomass material lotus leaf. *Chemical Engineering Journal* 171: 1-8.
27. Dawood S., Sen T. K. (2012). Removal of anionic dye Congo red from aqueous solution by raw pine and acid-treated pine cone powder as adsorbent: Equilibrium, thermodynamics, kinetics, mechanism and process design. *Water Research* 46: 1933-1946.

28. Al-Anber Z.A., Al-Anber M. A., Matouq M., Al-Ayed O., Omar N. M. (2011). Deffated Jojoba for the removal of Methylene blue from aqueous solution: Thermodynamic and kinetic studies. *Desalination* 276: 169-174.
29. Patil, S., Renukdas, S., Patel, N. (2011). Removal of Methylene blue, a basic dye from aqueous solutions by adsorption using teak tree (*Tectona grandis*) bark powder. *International Journal of Environmental Sciences* 1 (5).
30. Sajab, M. S., Chia, C. H., Zakaria, S., Khiew, P.S. (2013). Cationic and anionic modification of oil palm empty fruit bunch fibers for the removal of dyes from aqueous solutions. *Bioresource Technology* 128: 571-577.
31. Langmuir, I. (1918). The adsorption of gases on plane surfaces of glass, mica and platinum. *Journal of American Chemical Society* 40: 1361-1403.
32. Renugadev, N., Sangeetha, R., Lalitha, P. (2011). Effectiveness of an economic adsorbent in the adsorption of Methylene blue from an industrial dyeing effluent. *Advances in Applied Science Research* 2 (4): 629-641.
33. Freundlich, H.M.F., (1906). Uber die adsorption in lasugen. *Physical Chemistry* 57: 385-470.
34. Potgeiter, J., Potgeiter, V. K., Kalibatonga, P. (2005). Heavy metals removal from solution by Palygorskite clay. *Minerals Engineering*.
35. Mahvi, A. H., Maleki, A., Eslami, A. (2004). Potential of rice husk and rice husk ash for phenol removal in aqueous system. *American Journal of Applied Science* 1 (4) 321-326.
36. Singh, A. K., Singh, D. P., Pandey, K. K., Singh, V. N. (1998). "Wollastonite as adsorbent for removal of Fe (II) from water." *Journal of Chemical Technology* 42: 39.
37. Ho, Y.S., McKay, G. (1999). Pseudo-second order model for sorption processes. *Process Biochemistry* 34: 451-65.
38. Weber, W. J., Morris, J. C. J. (1963). Kinetics of adsorption on carbon from solutions. *Sanitary Engineering Division ASCE* 89: 31-60.
39. Ahmed, M. J., Dhedan, S. K. (2012). Equilibrium isotherms and kinetics modeling of Methylene blue adsorption on agricultural wastes-activated carbons. *Fluid Phase Equilibria* 317: 9-14.
40. Khaled, A., Nemr, A. E., El-Sikaily, A., Abdelwahab, O. (2009). Removal of Direct N Blue-106 from artificial textile dye effluent using activated carbon from orange peel: adsorption isotherm and kinetic studies. *Journal of Hazardous Materials* 165:100-110.
41. Vimonses, V., Lei, S., Jin, B., Chow, C. W. K., Saint, C. (2009). Adsorption of Congo red by three Australian kaolins. *Applied Clay Science* 43: 465-472.
42. Abramian, L., El-Rassy, H. (2009). Adsorption kinetics and thermodynamics of azo-dyes Orange II onto highly porous titania aerogel. *Chemical Engineering Journal* 150: 403-410.
43. Lynd, L. R., Wyman, C. E., Gerngross, T. U. (1999). Biocommodity engineering. *Journal of Biotechnology Progress* 15: 777-793.

The IISTE is a pioneer in the Open-Access hosting service and academic event management. The aim of the firm is Accelerating Global Knowledge Sharing.

More information about the firm can be found on the homepage:  
<http://www.iiste.org>

## CALL FOR JOURNAL PAPERS

There are more than 30 peer-reviewed academic journals hosted under the hosting platform.

**Prospective authors of journals can find the submission instruction on the following page:** <http://www.iiste.org/journals/> All the journals articles are available online to the readers all over the world without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. Paper version of the journals is also available upon request of readers and authors.

## MORE RESOURCES

Book publication information: <http://www.iiste.org/book/>

## IISTE Knowledge Sharing Partners

EBSCO, Index Copernicus, Ulrich's Periodicals Directory, JournalTOCS, PKP Open Archives Harvester, Bielefeld Academic Search Engine, Elektronische Zeitschriftenbibliothek EZB, Open J-Gate, OCLC WorldCat, Universe Digital Library, NewJour, Google Scholar

