Adsorption and Kinetic studies of dyeing *Clitoria ternatea* L. natural dye onto bamboo yarn

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Abstract- In the present study, the bamboo yarn is dyed with a natural dye extracted from Clitoria ternatea L.flower. The effect of adsorption mechanism on the dyeing Clitoria ternatea L. natural dyes onto bamboo yarn were investigated. It has been observed that the adsorption process of time in the range of 10-90 minutes, with maximum adsorption capacity at 60th minutes.Assessment of the effect of time on dye adsorption showed an increase in adsorption capacity with increasing time, with maximum adsorption at 60 minutes. Pseudo-first order, Pseudo-second order, and Intraparticle diffusion equations were employed to investigate adsorption rates. Pseudo-first order model provided the best fit indicating physisorption. The equilibrium adsorption data were fitted to Langmuir, Freundlich, Temkin, and Dubinin Radushkevish isotherm models. Langmuir isotherm model agreed well with the experimental data having high regression coefficients for dyeing bamboo yarn with dye concentration at 0.12 g/mL. These findings suggest that the application of natural dye from Clitoria ternatea L.flower onto bamboo yarn which is a new resource of the natural fiber in the industry is a good approach to get the desired dyeing, adsorption, and kinetic property.

Index Terms- Natural dye, Clitoria ternatea L., Adsorption, Kinetics, Bamboo yarn, Dyeing

## 1 INTRODUCTION

The use of natural colors has been part and parcel of our life since ancient times. The natural dyes have been used for many purposes such as the coloring of natural fibers wool, cotton and silk as well as fur and leather. The dyes were also used to color cosmetic products and to produce inks, watercolors and artists' paints. The use of natural dyes to color textiles declined rapidly after the discovery of synthetic dyes by Perkin in 1856 until they were virtually unused by 1900 [1]. Since natural dyes are biodegradable and less toxic and allergenic than synthetic dyes, they are considered to be environmentally friendly [2]. Natural dyes as naturally derived colorants and antimicrobial agents have more advantages over synthetic dyes in that they exhibit good biodegradability and compatibility with the environment [3]. Recently, interest in the use of natural dyes has been growing rapidly due to the result of stringent environmental standards imposed by environmental board and pollution control board of many countries in response to toxic and allergic reactions associated with synthetic dyes [4]. Research has shown that synthetic dyes are suspected of releasing harmful chemicals that are considered to be a high pollutant in both water and land which would be allergic, carcinogenic and detrimental to human health. *Clitoria ternatea* L., known by several common names including butterfly pea or blue pea, is a plant species belonging to the Fabaceae family. The flower petal of *Clitoria ternatea* L. is commonly used as a natural food colorant and healthy beverages around the world. *Clitoria ternatea* L., (Figure 1), a well-known plant drug in possess a wide range of pharmacological activities including antimicrobial, antipyretic, anti-inflammatory, analgesic, diuretic, local anesthetic, antidiabetic, insecticidal, blood platelet aggregation-inhibiting and for use as a vascular smooth muscle relaxing properties [5].

The most studied and the main colorant pigment of flower *Clitoria ternatea* L. reported are anthocyanin confirmed by HPLC and other spectral analysis [6][7] molecular structures are given in Figure 2. The major anthocyanin pigment of this plant has been found biologically active [7][8][9][10][11] but very little information is available on its dyeing properties, and hence can be explored as an effective and sustainable natural dye for coloration and surface finishing of textile materials to overcome the growing demands of textile industry. Recently, a lot of investigations have been undertaken on dyeing and functional finishing of textile materials along with the evaluations of thermodynamics and kinetic parameters [3][12][13][14][15]. Fundamental studies on adsorption kinetics and thermodynamics of dyeing processes are important for understanding the dyeing mechanisms and improving dyeing performance of natural dyes on various textile materials. An adsorption isotherm curve describes the phenomenon of retention of substances from aqueous media onto solid-phase at constant temperature and pH [16]. For this reason, present research deals with the application of *Clitoria ternatea* L., natural dye onto bamboo yarn with preliminary emphasis on kinetic and thermodynamic adsorption aspects. Also, build-up properties of *Clitoria ternatea* L. were carried out using Alum as the mordant and emission spectral adsorption characteristics of bamboo yarn were investigated and compared with that of the blank dyed samples.

Figure 1 Flower of *Clitoria ternatea* L.,
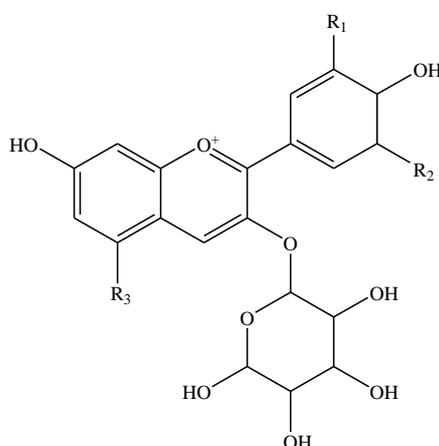
Figure 2 Common chemical structure of anthocyanin [17]

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2   EXPERIMENTAL

2.1   Plants material

The flowers of *Clitoria ternatea* L. was obtained from the backyard at Taman Mahkota Aman, Kuantan Pahang. The raw material was kept dried in the oven at the laboratory and then was ground.

2.2   Fibre Material

Pusat Tenun Pekan, Pahang provided the bamboo yarns, which are made of 100% bamboo fibers. Figure 2 shows the chemical structure of cellulose in bamboo fiber.

2.3   Chemical and Reagents

Both sodium hydroxide and chloric acid are analytical reagent grade. anthocyanin standard was purchased from Sigma-Aldrich.

2.4   Dye Extraction

The flowers of *Clitoria ternatea* L. was cleaned and dried in an oven at a low temperature in order to remove all the moisture content in the flower. Then, the flower was ground into small pieces, about 1mm, to increase the surface area. Then, the blue natural dye was extracted by applying ratio 0.12 g/mL corresponding to the ratio of 1.2 g of raw material to 10 mL of water [18][19]. The mixture was then centrifuged at 4 ℃, 10000rpm for 15 minutes [20]. The mixture was filtered to collect the supernatant dye. Finally, filtration of the supernatant was done by using Whatman filter paper and pH was adjusted by HCl and NaOH if needed [18]. The resulting extract was used for the further experiment.

2.5   Dyeing Procedure

The absorbance of *Clitoria ternatea* L., dye solution was measured using UV-Vis Spectrophotometer, and the reading was recorded. The experiment continued dyeing bamboo yarn using the ratio of 1:100 for the weight bamboo yarn in the *Clitoria ternatea* L., dye solution. The bamboo yarn in the yellow dye solution was then agitated in the incubator shaker KS4000i for about 100rpm at room temperature. The sample with a pH value of 6.5 was left 30 minutes, and the reading of dye solution after the dyeing process was recorded. The pH was adjusted by HCl and NaOH when needed. The bamboo yarn that was used in this has to be washed thoroughly with distilled water. The dyed bamboo yarn was then dried and soaked in a 25% aluminum sulfate (Alum) solution, which acts as a mordant. The mordant solution was heated up to 70˚C and then left to cool for 45 minutes. The bamboo yarn was then removed from the mordant solution and rinsed well with distilled water.

2.6   Calculations of anthocyanin pigments

Total anthocyanin content was determined spectrophotometrically at 525 nm according to the standard calibration curve. The absorbances, as well as the absorbance spectra of Clitoria ternatea L., dye solutions, were measured with the UV–vis spectrophotometer (U-1800). Total anthocyanins were quantified using equivalents cyanidin-3-glucoside (mg/L) [21]. MW is the molecular weight of cyanidin (449.2 g/mol), V is the volume of extract, DF is dilution factor, ε is the mean molar mean molar absorptivity (29,600 L/mol^{-1} cm^{-1}), and L is the path length (1 cm).

$$Total\ anthocyanin\ content\ \left(\frac{mg}{L}\right) = \frac{A \times MW \times DF}{\varepsilon \times L} \times 1000 \qquad (1)$$

The difference in betacyanin content can be determined using the following formula:

$$BC(before) - BC(after) = Betacyanin\ content\ on\ BY \qquad (2)$$

2.7   Adsorption Procedure

Different dye concentration solutions were prepared using different dilution factor of the dye. Table 1 shows the dilution factors, which are 0.93, 0.87, 0.80, 0.73 and 0.67. This analysis used distilled water as a blank solution The optical density of the solution is then measured by adding the dye solution into the cuvette using micropipette before placing the cuvette into the spectrophotometer. The wavelength is set at 525 nm for *Clitoria ternatea* L., dye. The optical density for each dye concentration was recorded. 0.2 g of bamboo yarn was soaked into several 20 ml test tubes containing dye solution of different concentrations. They are left for 90 minutes as it is the equilibrium time for dye solution and another 24 hours for the drying process. After 90 minutes, the fabrics are removed from the test tubes, and the dye solution that remained in the test tubes will undergo the same process to determine the optical density of the solution using a spectrophotometer. After obtaining the optical density readings for both before and after adsorption process, the values were introduced to the equation to calculate the total anthocyanin content in the *Clitoria ternatea* L., dye that was adsorbed by the bamboo yarn. The amount of dye adsorbed per unit for the weight of bamboo yarn at equilibrium q_e (mg/ g bamboo yarn) was calculated in equation (3), where C_0 is the initial dye concentration (mg/L) in the solution. C_e is the unbound dye concentration (mg/L) at equilibrium. V is the initial volume (L) of the dye solution,m is the dry adsorbent dosage (g), and W is the weight of bamboo yarn (g) [22][23].

$$q_e = \frac{(C_0 - C_e)V}{W} \qquad (3)$$

Table 1 Water and Dye Ratio for Dilution Factor

Dilution Factor	Water (mL)	Dye (mL)
0.93	2	28
0.87	4	26
0.80	6	24
0.73	8	22
0.67	10	2

3   RESULTS AND DISCUSSION

3.1   Effect of time on adsorption equilibrium

Since the adsorption time reached equilibrium in the 60th minutes for anthocyanin, the concentration of dye in the solution at equilibrium time will be used as C_e. From Figure 3 the exact amount of anthocyanin adsorbed onto bamboo yarn has been determined. The equilibrium time was reached at the minute 60 minutes for adsorption anthocyanin extracted from the dye of *Clitoria ternatea* L., It confirmed that the strong electrostatic attractive force between the positively charged anthocyanin and the negatively charged bamboo yarn surfaces was the main driving force for adsorption. Then the amount of anthocyanin adsorbed onto the bamboo yarn increases gradually with increasing contact time until the maximum amount is reached, which means that the adsorption equilibrium was reached. At this points, the amount of anthocyanin adsorbed onto the bamboo yarn is in the state of dynamic equilibrium. In another word, fast diffusion into the external surface of the adsorbent was occurred by a fast pore diffusion into the intra particle matrix to attain rapid equilibrium. Since the equilibrium was reached at 60 minutes, the experiment on the adsorption of anthocyanin adsorbed onto the bamboo yarn at different concentration dilution factors was done for 60 minutes as well.
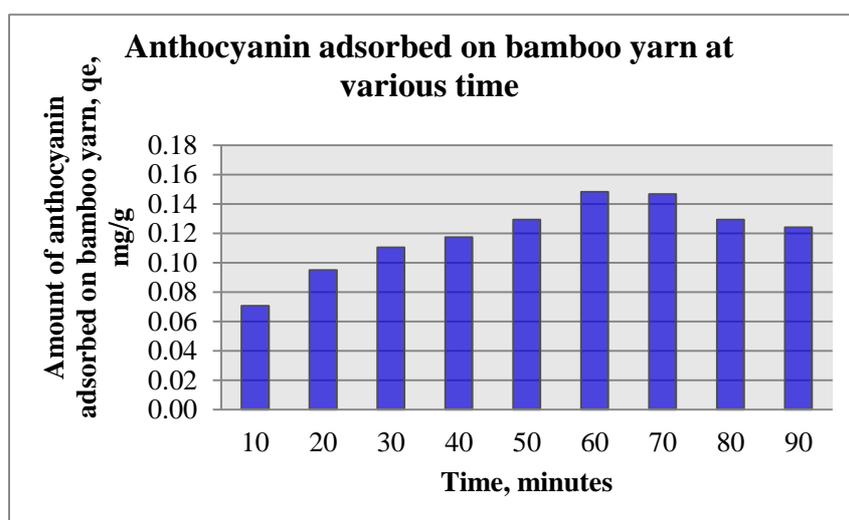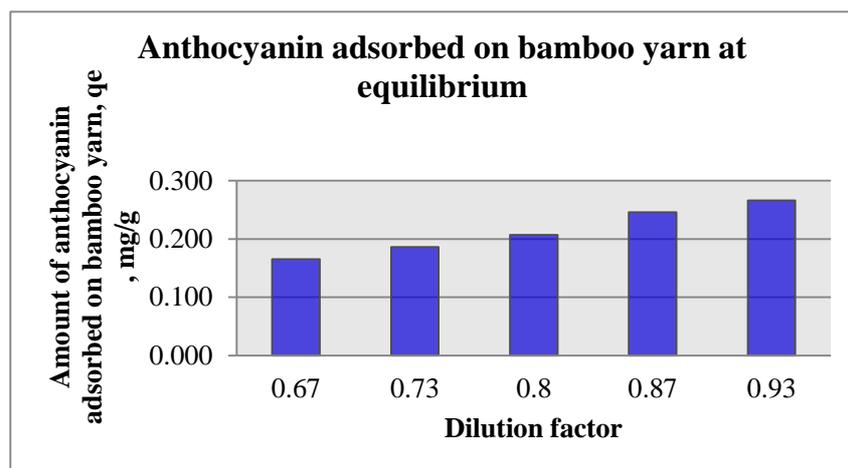

Figure 3 Amount of anthocyanin adsorbed onto bamboo yarn at different time intervals

3.2   Effect of dye bath concentrations on adsorption at equilibrium time

The graph of the amount of dye adsorbed versus dilution factor was then plotted. According to the results shown in Figure 4, the dye baths of the *Clitoria ternatea* L., dye concentration plays an important role in the adsorption of colorant pigments onto bamboo yarn. The amount of anthocyanin adsorbed onto bamboo yarn increases with an increase in dye bath concentration at a constant amount of bamboo yarn. In other words, at lower dye bath concentrations, the ratio of number anthocyanin molecules to the available adsorption site is low. While at higher dye bath concentration, the ratio becomes higher and subsequently the adsorption of anthocyanin depends on the dye bath concentration.

Figure 4 Amount of anthocyanin adsorbed onto bamboo yarn at equilibrium time and various dilution factors
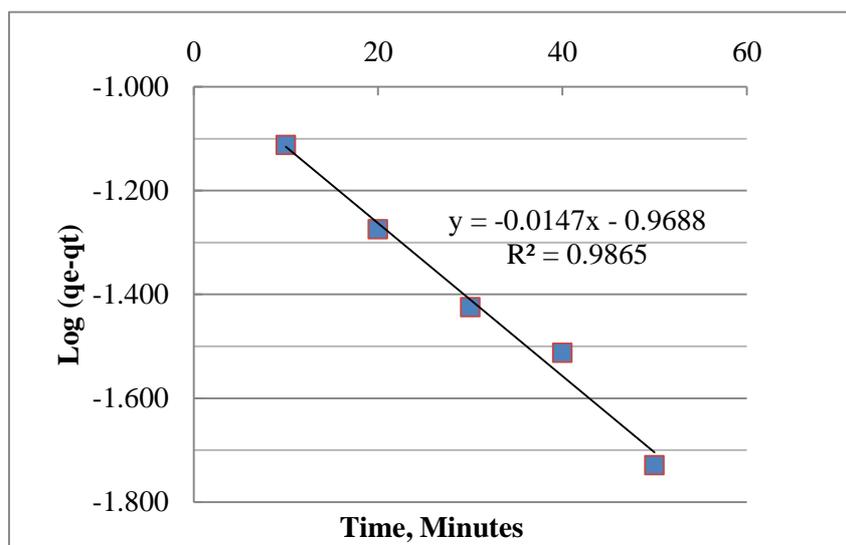
3.3   Adsorption kinetics

Pseudo-first order model assumes that the adsorption of colorant pigments onto bamboo yarn occurs due to a concentration difference of the adsorbate between adsorbent surface and the solution. Therefore, this process occurs only by the external mass transfer coefficient [24]. The Lagergren rate equation is the first rate equation for adsorption in a liquid or solid system based on solid capacity. It is given in equation 4.

$$\frac{dq_t}{dt} = k_1 \left(q_e - q_t \right) \tag{4}$$

After integration on the both sides of the equation and applying conditions for $q_t=0$ at $t=0$ and $q_t=q_t$ at $t=t$, the equation 5 can be used for the kinetic analysis of experimental results.

$$log \left(q_e - q_t \right) = log \, q_e - \frac{k_1}{2.303} \tag{5}$$

Where the q_e is the amount of anthocyanin adsorbed onto bamboo yarn at equilibrium (mg/g), q_t is a number of colorant pigments adsorbed onto bamboo yarn at time t (mg/g) and k_1 is the equilibrium rate constant of pseudo-first order kinetic (min^{-1}). From the equation, a linear curve of the log (q_e-q_t) versus t was plotted. The slopes then correspond to the value of k_1. The data are shown in Figure 5 and apparently the adsorption of the colorant pigments of anthocyanin onto bamboo yarn follow pseudo-first-order model. The k_1, the calculated q_e ($q_{e,cal}$) and the coefficient of determination (R^2) were calculated and are tabulated in Table 2.

Figure 5 Pseudo-first order kinetic model for anthocyanin adsorption onto bamboo yarn at

60°C

Then, the pseudo-second-order equation was attempted to fit the adsorption of colorant pigments onto bamboo yarn data. The pseudo-second-order kinetic are equation is given below.

$$\frac{dq_t}{d_t} = k_2 \left[(q_e - q_t) \right]^2 \tag{6}$$

Where k_2 is the equilibrium rate constant of pseudo-second order kinetic model (g mg^{-1}min^{-1}). After integrating   , the following equation can be obtained.

$$\frac{1}{q_t} = \frac{1}{(k_2 \, q_e{}^2) + (\frac{1}{q_e})t} \tag{7}$$

To determine the applicability of the model, linear plots of t/q_t versus t for the adsorption of the colorant pigments of anthocyanin onto bamboo yarn was plotted to obtain the rate parameters and shown in Figure 6. From this figure, the adsorption of the colorant pigments of anthocyanin onto BY does not follow pseudo-second order model. The k_2, the calculated q_e ($q_{e,cal}$) and the coefficient of determination (R^2) were calculated and are given in Table 2.
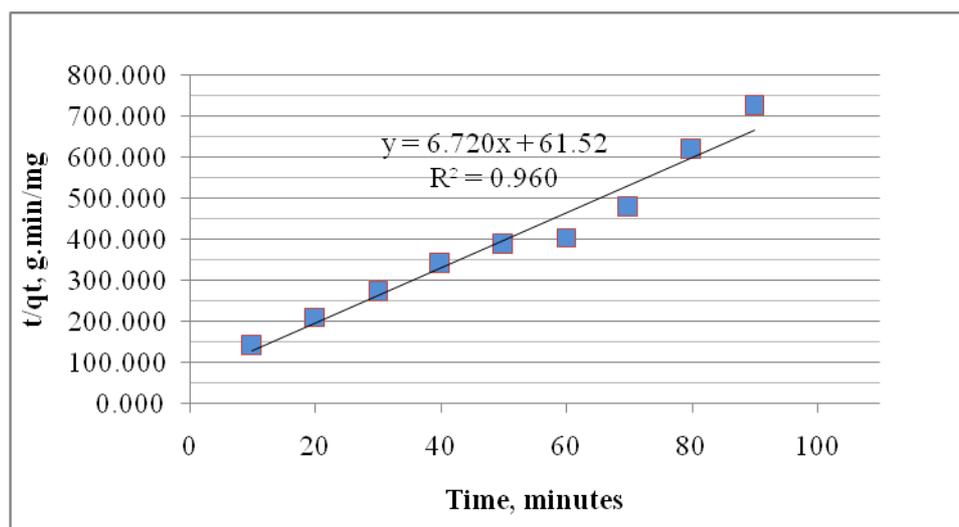
Figure 6 Pseudo-second order kinetic model for anthocyanin adsorption onto bamboo yarn at 60 °C

From the experimental q_e ($q_{e,exp}$) value obtained agree with the calculated ones ($q_{e,cal}$) for adsorption of anthocyanin pigment. Its show a goof linear fit using a pseudo-first-order kinetic model which could be seen as the experimental q_e ($q_{e,exp}$) value obtained was agreed with the calculated ones ($q_{e,cal}$) and the value of the coefficient of determination (R^2) was relevant. Therefore, this suggests that the anthocyanin adsorption onto bamboo yarn occurred by the internal mass transfer mechanism and it indicates that the reaction is more inclined towards physisorption. The similar resulted in adsorption of dyeing of woolen yarn by *Terminalia chebula* extract reported by [15].

Table 2 Kinetic parameters for colorant pigments adsorption onto bamboo yarn

$q_{e,exp}$	Pseudo first order			Pseudo-second order		
	$q_{e,cal}$	k_1	R^2	$q_{e,cal}$	k_2	R^2
0.148	0.033	0.032	0.986	0.368	0.036	0.143

To investigate the internal diffusion mechanism during the adsorption of the colorant pigments onto bamboo yarn, the intra-particle diffusion equation was used. The adsorption was investigated by the Weber and Morris model, also known as intraparticle diffusion model, which assumes the adsorption mechanism described elsewhere [25] It is considered that the adsorption usually controlled by an external film resistance and or mass transfer is controlled by internal or intra particle diffusion [24]. The possibility of intra particle diffusion resistance affecting adsorption was explored using equation 8.

$$q_t = k_p \, t^{(1/2)} + C \tag{8}$$

Where k_p is the intra particle diffusion rate constant (mg.g^{-1}.min^{-1}) and C is the internal diffusion coefficient.

It is determined from the linear graph of qt versus (time)$^{1/2}$ In some cases, three linear sections on a plot of q_t versus $t^{1/2}$ for anthocyanin can be identified. Figure 7 shows the plots for the anthocyanin adsorption onto bamboo yarn. The first portion represents external surface adsorption or instantaneous adsorption stage. The second portion is a gradual adsorption stage where the intra particle diffusion is the controlling factor and the last portion is a final equilibrium stage where the intra particle diffusion starts to decelerate due to the extremely low solute concentration in the solution. The plots of qt versus (time)$^{1/2}$ show multi-linearity. According to the plots, each portion represents a distinct mass transfer mechanism. In the colorant pigments adsorption on bamboo yarn, an initial portion relative to the boundary layer diffusion (film diffusion) was observed from 10-60 minutes. Then the mass transfer step in colorant pigments adsorption onto bamboo yarn was the film diffusion. This may occur due to the presence of a rigid and nonporous surface and low value of the surface area of bamboo yarn. In addition, the colorant pigments molecular size may be higher than average pore radius of bamboo yarn, inhibiting the internal diffusion. The values of C in the equation 9 is 0.105. According to this model, a plot of uptake are linear and the adsorption process involved the intra particle diffusion. The plots do not pass through the origin where it indicates that some degree of boundary layer control. It also indicates that the intraparticle diffusion is not the only rate-limiting step but also other kinetic models may control the rate of adsorption and all of which may be operating simultaneously.
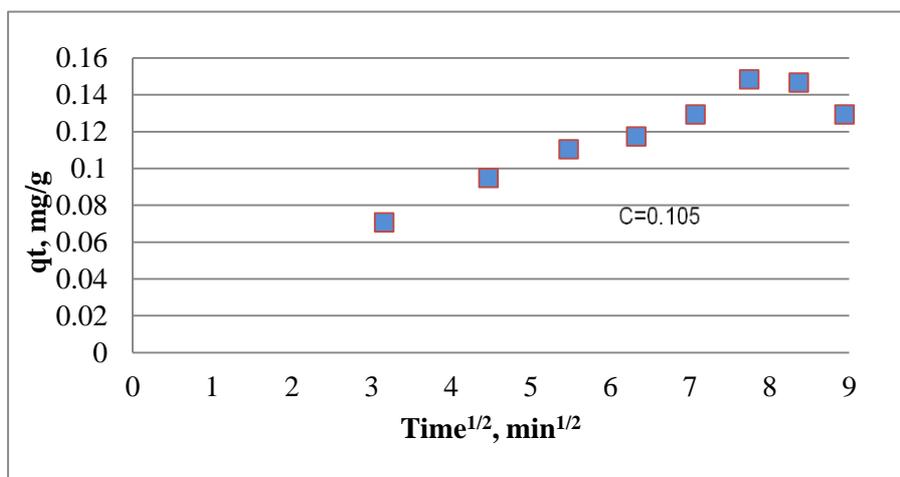
Figure 7 Intraparticle diffusion model for anthocyanin adsorption onto bamboo yarn

3.4   Adsorption isotherms

The equilibrium isotherm was important in predictive modeling for analysis and design of adsorption systems for bamboo yarn. So, the equilibrium adsorption data was fitted to Langmuir, Freundlich, Temkin and Dubinin-Radushkevish isotherm models. The linear expression of Langmuir isotherm is as follows:

$$\frac{1}{q_e} = \frac{1}{q_{max}} + \frac{1}{q_{max}K_LC_e} \tag{9}$$

Where q_e and C_e are the amount of dye adsorbed per gram of bamboo yarn (mg/g) and dye concentration (mg/mL) in the dye bath at equilibrium, respectively. q_{max} (mg/g bamboo yarn) is the maximum dye adsorbed per unit weight of bamboo yarn for complete monolayer adsorption. K_L is Langmuir constant related to the affinity of binding sites (mL/mg). Further, description of Langmuir isotherm can be also be expressed in terms of the dimensionless constant separation factor for equilibrium parameter, R_L [15], defined as follows:

$$R_L = \frac{1}{1 + K_L\, c_0} \tag{10}$$

Freundlich isotherm is also an adsorption isotherm, in which there is a curve relating the concentration of a solute on the surface of adsorbent to the concentration of solute which is present in the liquid in which it is in contact and expressed as follows:

$$log\, q_e = logK_f + \frac{1}{n} logC_e \tag{11}$$

K_f is the Freundlich adsorption constant and n is that of the adsorption intensity. K_f and n can be determined from slope and intercept of linear plot $log q_e$ versus $log C_e$. The value of n >1 represents favorable adsorption. This isotherm contains a factor that explicitly taking into the account of adsorbent–adsorbate interactions. By ignoring the extremely low and large value of concentrations, the model assumes that heat of adsorption (a function of temperature) of all molecules in the layer would decrease linearly rather than logarithmic with coverage [26]. The linear form of Temkin isotherm equation is represented as:

$$q_e = \frac{RT}{b_T} lnA_T + \frac{RT}{b_T} lnC_e \tag{12}$$

$$B = \frac{RT}{b_T} \tag{13}$$

K_T (L/mg) is the equilibrium binding constant of Temkin isotherm model corresponding to the maximum binding energy. Constant B_1 is related to the heat of adsorption. RT was associated with the adsorption heat. A_T was the equilibrium constant corresponding to the maximum bind energy. Dubinin–Radushkevich isotherm is generally applied to express the adsorption mechanism with a Gaussian energy distribution onto a heterogeneous surface [26]. The model has often successfully fitted high solute activities and the intermediate range of concentrations data well. This isotherm is used to determine whether the adsorption is chemical or physical in nature [24]. The Linear form of Dubinin–Radushkevich equation is given below:

$$ln\, q_e = ln\, q_D - \beta_D \; \varepsilon^2 \tag{14}$$

Where q_e is the adsorption capacity at equilibrium (mol/g), q_D is Dubinin–Radushkevich monolayer saturation capacity (mol/g), β_D is constant related to the mean free energy of adsorption per mole of the adsorbate (mol²/J²) and ε^2 is polyani potential which is related to equilibrium concentration (J²/mol²).

$$\varepsilon = RT \, ln(1 + {}^1\!/_{C_e}) \tag{16}$$

$$E_{DR} = \frac{1}{\sqrt{(2\beta_D)}} \tag{17}$$

R is the gas constant (8.314 J/mol.K), T is absolute temperature (K) and Ce is the equilibrium dye concentration. E_{DR} parameter is useful for estimating the type of adsorption interaction. If the adsorption process is primarily physical in nature, such as Van der Waals forces, the average free energy is typically in the range of 1-8 kJ/mol. If E_{DR} is between 8-16 kJ/mol, the adsorption process is chemisorption via ion exchangeTo find the most appropriate model to describe the adsorption behaviors of *Clitoria ternatea* L., natural dye onto bamboo yarn, all the isotherms were fitted by using linear least-squares fitting procedure. By comparing correlation coefficients, R^2 of all isotherm models presented in Table 3, it is concluded that Langmuir isotherm model (Figure 8) gave the best fit to experimental data of thermodynamic adsorption of *Clitoria ternatea* L., onto bamboo yarn compared Freundlich (Figure 9), Temkin (Figure 10) and Dubinin- Radushkevich (Figure 11) isotherm models. R_L for anthocyanin was observed within 1 and 0 (0.698) which indicating the adsorption is favorable. The magnitude of the exponent 1/n gives an indication of the favorability of adsorption. The value of n>1 represents favorable adsorption [15]. In this research, the value of n was observed was less that 1(0.007) which indicating unfavorable. Low b_T values indicate that the interaction is neither purely ion-exchange nor physisorption. For anthocyanin adsorption onto bamboo yarn tested, the mean free energy of adsorption calculated for the interaction is 5.00 kJ/mol, which accounts for physical adsorption. Thus, Van der Waals forces lead to EDR in the range of 1–8 kJ/mol and the nature of adsorption was proved by pseudo-first order kinetic model.

Table 3 Kinetic parameters for the adsorption of *Clitoria ternatea* L., dye onto bamboo yarn

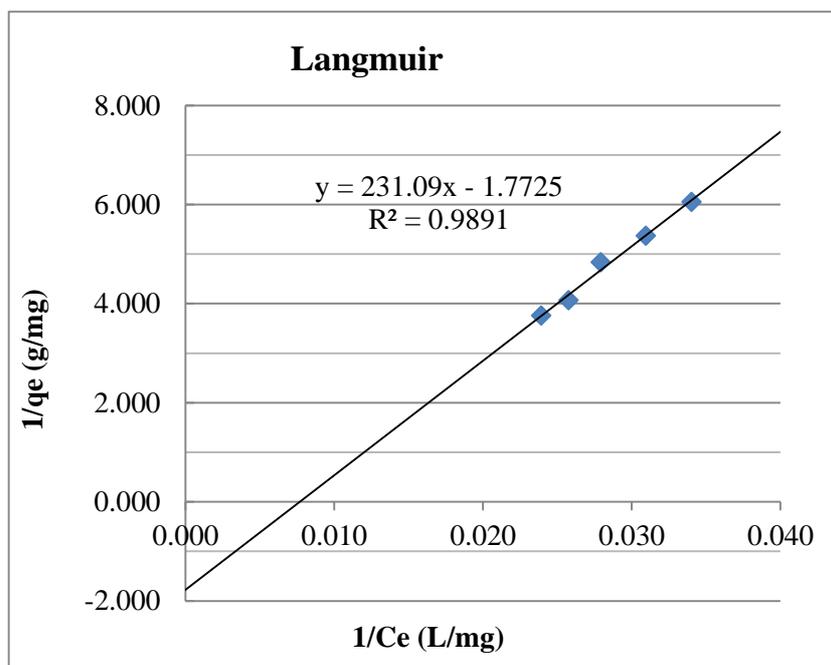| Langmuir	R^2	q_{max} (mg/g)	K_L (L/mg)	R_L
	0.989	0.564	0.767	0.698
Freundlich	R^2	n	K_F (L/g)	
	0.986	0.007	-1.035	
Temkin	R^2	A_T (L/mg)	B	b_T (KJ/mol)
	0.974	-0.068	3.332	3.878
Dubinin-Radushkevish	R^2	q_D (mol/g)	β_D (mol^2/J^2)	E_{DR} (kJ/mol)
	0.985	1.251	2.00E-08	5.00

Figure 8 Langmuir isotherm of adsorption of *Clitoria ternatea* L., dye onto bamboo yarn
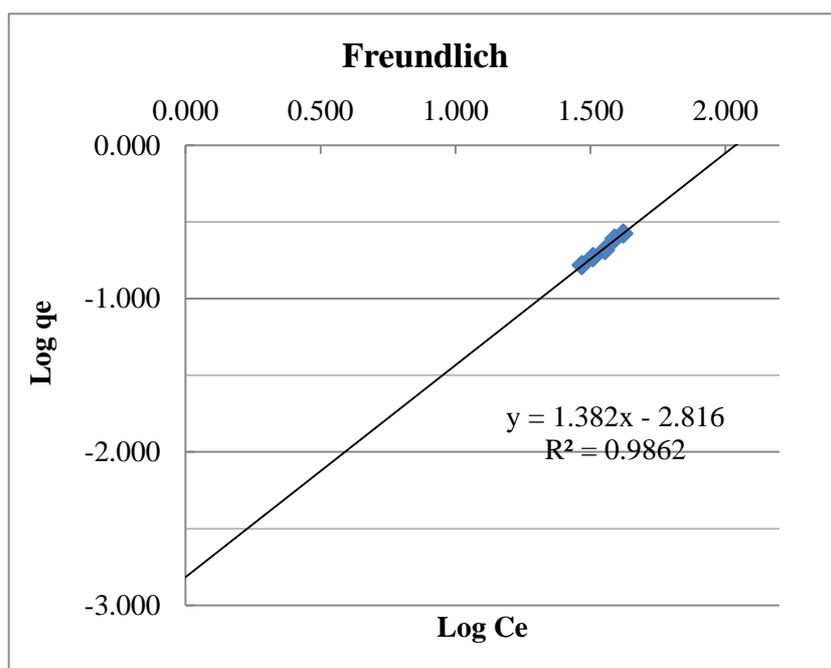

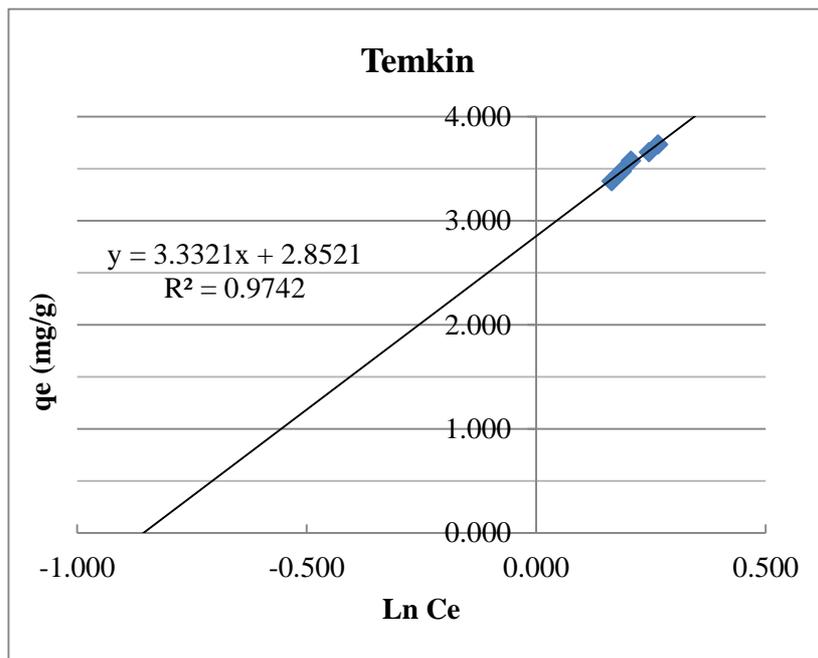**Figure 9 Freundlich isotherm of adsorption of *Clitoria ternatea* L., dye onto bamboo yarn**

Figure 10 Temkin isotherm of adsorption of *Clitoria ternatea* L., dye onto bamboo yarn
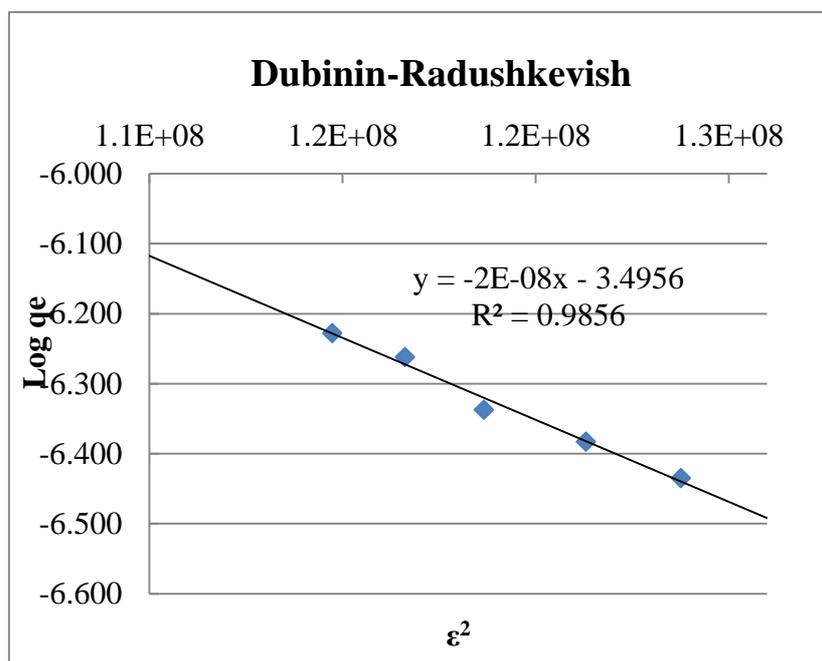

Figure 11 Dubinin-Radushkevich isotherm of adsorption of *Clitoria ternatea* L., dye onto

bamboo yarn

4   CONCLUSIONS

The adsorption of *Clitoria ternatea* L., dye onto bamboo yarn was studied with the aim of improving dyeing performance and understanding the dyeing mechanisms of natural dyes on bamboo yarn textile materials. The adsorption process was investigated in the time range of 10-90 minutes, with maximum adsorption capacity at 60th minutes. The kinetic data was best fitted to Pseudo-first order kinetic model with highest regression coefficient, implying that the nature of adsorption process was physisorption suggesting that the main operating forces and dyeing mechanism are controlled by the internal mass transfer mechanism. Adsorption isotherms were best fitted to Langmuir isotherm with high regression coefficient and Temkin isotherm models with least regression coefficient Langmuir isotherm model successfully helps in understanding adsorption mechanism of *Clitoria ternatea* L., dye onto bamboo yarn. The extent of adsorption linearly increased with increasing dye concentration showing build-up properties. It is concluded that extract of *Clitoria ternatea* L., dye may be developed as a natural eco-friendly dye for cellulosic fibers.

ACKNOWLEDGEMENT

References

[1] M. Mirjalili, K. Nazarpoor, and L. Karimi, "Eco-friendly dyeing of wool using natural dye from weld as co-partner with synthetic dye," *J. Clean. Prod.*, vol. 19, no. 9, pp. 1045–1051, 2011.

[2] N. Punrattanasin, M. Nakpathom, B. Somboon, N. Narumol, N. Rungruangkitkrai, and R. Mongkholrattanasit, "Silk fabric dyeing with natural dye from mangrove bark (Rhizophora apiculate Blume) extract," *Ind. Crops Prod.*, vol. 49, pp. 122–129, 2013.

[3] Y. Zhou, J. Zhang, R.-C. Tang, and J. Zhang, "Simultaneous dyeing and functionalization of silk with three natural yellow dyes," *Ind. Crops Prod.*, vol. 64, pp. 224–232, 2015.

[4] D. L. R. B and D. Ravi, "Extraction of Natural Dyes From Selected Plant Sources and Its Application in Fabrics," *Int. J. Text. Fash. Technol.*, vol. 3, no. 2, pp. 53–60, 2013.

[5] P. K. Mukherjee, V. Kumar, N. S. Kumar, and M. Heinrich, "The Ayurvedic medicine Clitoria ternatea—From traditional use to scientific assessment," *J. Ethnopharmacol.*, vol. 120, no. 3, pp. 291–301, 2008.

[6] S. B. Patil, M. S. Kondawar, R. R. Shah, N. S. Naikwade, and C. S. Magdum, "Use of flower extract of Clitoria ternata L . as a compound indicator," vol. 2, no. 2, pp. 241–242, 2009.

[7] K. Kogawa, K. Kazuma, N. Kato, N. Noda, and M. Suzuki, "Biosynthesis of malonylated flavonoid glycosides on the basis of malonyltransferase activity in the petals of Clitoria ternatea," *J. Plant Physiol.*, vol. 164, no. 7, pp. 886–894, 2007.

[8] J. B. Morris, "Characterization of butterfly pea (Clitoria ternatea L.) accessions for morphology, phenology, reproduction and potential nutraceutical, pharmaceutical trait utilization," *Genet. Resour. Crop Evol.*, vol. 56, no. 3, pp. 421–427, 2009.

[9] P. Pasukamonset, O. Kwon, and S. Adisakwattana, "Alginate-based encapsulation of polyphenols from Clitoria ternatea petal flower extract enhances stability and biological activity under simulated gastrointestinal conditions," *Food Hydrocoll.*, vol. 61, pp. 772–779, 2016.

[10] J. Singh and K. N. Tiwari, "In vitro plant regeneration from decapitated embryonic axes of Clitoria ternatea L.—An important medicinal plant," *Ind. Crops Prod.*, vol. 35, no. 1, pp. 224–229, 2012.

[11] W. Phrueksanan, S. Yibchok-anun, and S. Adisakwattana, "Protection of Clitoria ternatea flower petal extract against free radical-induced hemolysis and oxidative damage in canine erythrocytes," *Res. Vet. Sci.*, vol. 97, no. 2, pp. 357–363, 2014.

[12] H. Tayebi, M. E. Yazdanshenas, A. Rashidi, R. Khajavi, and M. Montazer, "The Isotherms , Kinetics , and Thermodynamics of Acid Dye on Nylon6 with Different Amounts of Titania and Fiber Cross Sectional Shape," *J. Eng. Fiber. Fabr.*, vol. Volume 10, no. Issue 1, pp. 97–109, 2015.

[13] J. Shen, P. Gao, and H. Ma, "The effect of tris(2-carboxyethyl)phosphine on the dyeing of wool fabrics with natural dyes," *Dye. Pigment.*, vol. 108, pp. 70–75, 2014.

[14] P. B. Tayade and R. V. Adivarekar, "Adsorption kinetics and thermodynamic study of Cuminum cyminum L. dyeing on silk," *J. Environ. Chem. Eng.*, vol. 1, no. 4, pp. 1336–1340, 2013.

[15] M. Shabbir *et al.*, "An eco-friendly dyeing of woolen yarn by Terminalia chebula extract with evaluations of kinetic and adsorption characteristics," *J. Adv. Res.*, vol. 7, no. 3, pp. 473–482, 2016.

[16] L. J. Rather, Shahid-ul-Islam, M. A. Khan, and F. Mohammad, "Adsorption and Kinetic studies of Adhatoda vasica natural dye onto woolen yarn with evaluations of Colorimetric and Fluorescence Characteristics," *J. Environ. Chem. Eng.*, vol. 4, no. 2, pp. 1780–1796, 2016.

[17] H. Wang, P. Li, and W. Zhou, "Dyeing of Silk with Anthocyanins Dyes Extract from Liriope platyphylla Fruits," *J. Text.*, vol. 2014, pp. 1–9, 2014.

[18] A. Suebkhampet and P. Sotthibandhu, "Effect of Using Aqueous Crude Extract From Butterfly Pea Flowers (Clitoria Ternatea L .) As," vol. 19, no. 1, pp. 15–19, 2012.

[19] R. Kanchana, A. Fernandes, B. Bhat, S. Budkule, S. Dessai, and R. Mohan, "Dyeing of textiles with natural dyes - An eco-friendly approach," *Int. J. ChemTech Res.*, vol. 5, no. 5, pp. 2102–2109, 2013.

[20] J. Makasana, B. Z. Dholakiya, N. A. Gajbhiye, and S. Raju, "Extractive determination of bioactive flavonoids from butterfly pea (Clitoria ternatea Linn.)," *Res. Chem. Intermed.*, 2016.

[21] Y.-Z. Pan *et al.*, "Flavonoid C-glycosides from pigeon pea leaves as color and anthocyanin stabilizing agent in blueberry juice," *Ind. Crops Prod.*, vol. 58, pp. 142–147, 2014.

[22] V. Sivakumar, J. L. Anna, J. Vijayeeswarri, and G. Swaminathan, "Ultrasound assisted enhancement in natural dye extraction from beetroot for industrial applications and natural dyeing of leather," *Ultrason. Sonochem.*, vol. 16, no. 6, pp. 782–789, 2009.

[23] R. Bu, F. Chen, J. Li, W. Li, and F. Yang, "Adsorption capability for anionic dyes on 2-hydroxyethylammonium acetate-intercalated layered double hydroxide," *Colloids Surfaces A Physicochem. Eng. Asp.*, vol. 511, pp. 312–319, 2016.

[24] C. Wei and L. O. Brien, "Removal of Acid Yellow 25 Dye onto Chitin Extracted from Waste Crab legs and Study of Adsorption Isotherms and Kinetics of AY25 Dye Adsorption by Inoka Kumari Pathiraja , Bachelor of Science A Thesis Submitted in Partial Fulfillment of the Requirements fo," 2014.

[25] P. Benjwal, R. Sharma, and K. K. Kar, "Effects of surface microstructure and chemical state of featherfiber-derived multidoped carbon fibers on the adsorption of organic water pollutants," *Mater. Des.*, vol. 110, pp. 762–774, 2016.

[26] A. . Dada, A. . Olalekan, A. . Olatunya, and O. Dada, "Langmuir , Freundlich , Temkin and Dubinin – Radushkevich Isotherms Studies of Equilibrium Sorption of Zn 2 + Unto Phosphoric Acid Modified Rice Husk," *IOSR J. Appl. Chem.*, vol. 3, no. 1, pp. 38–45, 2012.