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Electrospun silver modified polyarylonitrile-activated carbon composite fibers: Methylene blue adsorption and antibacterial activity

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Abstract

Silver modified polyacrylonitrile-activated carbon (Ag-PAN-AC) composite fibers containing various AC concentrations were prepared by using an electrospinning process. Ag-PAN nanoparticles were initially prepared via in-situ reduction of silver nitrate using hydrazinium hydroxide as a reducing agent. The influence of AC contents on fiber morphology, methylene blue (MB) adsorption and antibacterial activity were investigated. Ag-PAN-AC composite fibers had rough and porous surfaces with an average fiber diameter of 200-250 nm. The size of fibers slightly decreased with increasing bead fibers when the dosage of AC increased. The Ag-PAN-AC composite fibers of AC composite fibers of AC increased.

exhibited the highest antibacterial activity against *Staphylococcus aureus* (*S. aureus*) due to the synergetic effect of AC and large surface area of fibers. The MB adsorption isotherm was Langmuir isotherm and the kinetic data fitted well with the pseudo second order model. The obtained results suggested that Ag-PAN-AC composite fibers could be promising candidates as dye adsorbents with antibacterial activity.

Keywords: polyacrylonitrile, activated carbon, silver nanoparticle, composite fiber, electrospinning

Introduction

Electrospinning is a well-known technique to produce continuous fibers from various polymers with sub-micron to nanometer sizes in web forms¹. This process uses an electric field to draw a solution from the tip of a needle to a collector. Solvent evaporation takes place from the charged fibers on the way to the collector, leaving behind non-woven mat fibers. Various factors can affect the production of electrospun fibers such as viscosity, elasticity, conductivity, surface tension, gap distance between the needle tip and the collector, applied voltage, hydrostatic pressure in the solution container, temperature, humidity and air flow. One of the most important parameters in electrospinning is the fiber diameter. A higher solution viscosity results in a larger fiber diameter². Another problem encountered in electrospinning is the formation of defects such as beads and pores, which may occur in polymer electrospun fibers^{3, 4}. The charge ions in the polymer solution greatly influence fiber formation. As the charges carried by the jet increase, higher elongation forces are imposed on the jet under the electrical field, resulting in smaller bead and thinner fibers⁵. Electrospun fibers have a variety of potential applications including sensors⁶, tissue engineering scaffolds⁷, wound dressings⁸, membranes⁹, and reinforced nanocomposites¹⁰ due to their large specific surface area, high fiber aspect ratio, high porosity and high degree of interconnection.

Ag nanoparticles are extensively used in anti-microbial applications because they are broad spectrum biocidal agents that are effective against bacteria, fungi and viruses but safe for human body¹¹. Recently, Ag-containing electrospun nanofibers have been of great interest as a novel form of anti-microbial material due to the combination of the high specific surface area and fineness of electrospun nanofibers with the biocidal activity of Ag nanoparticles¹²⁻¹⁶.

AC is a highly porous material and extensively used to remove a variety of pollutants such as dyes, heavy metals, pesticides and gases due to its large specific surface area and high adsorption capacity¹⁷⁻¹⁹. Contaminated water by dyes poses a tremendous threat to human health and environment because most of dyes are stable to heat, light, oxidizing agents and aerobic digestion²⁰. Methylene blue (MB) is a cationic dye, commonly used for dyeing cotton, wool and silk. It has a hazardous effect on humans and animals causing eye burns, cyanosis, convulsions, nausea, and diarrhea²¹.

In this study, the Ag modified PAN nanoparticles were prepared via in-situ reduction of silver nitrate using hydrazinium hydroxide as a reducing agent. Ag-PAN-AC solutions containing different AC concentrations were used to prepare composite fibers by electrospinning process. The effect of AC contents on viscosity and conductivity of spinning solution, fiber morphology, Ag content, MB adsorption and antibacterial activity against *S. aureus* of Ag-PAN-AC composite fibers were determined.

Experimental procedure

Materials

Polyacrylonitrile (PAN, average molecular weight of 150,000) supplied from Sigma-Aldrich was used as a base material. AC (CGC-11A 200C) was purchased from Gigantic Carbon Co., Ltd. with 1000-1100 m² g⁻¹ (N₂ BET method) surface area and 74 μ m average particle size. N,N-dimethylformamide (DMF) purchased from Labscan was utilized as a solvent for the preparation of Ag-PAN nanoparticles and spinning solutions. Silver nitrate (AgNO₃), hydrazinium hydroxide (N₂H₅OH) and acetone obtained from Analar Normapur, Carlo Erba and Labscan, respectively were used for synthesis of Ag-PAN nanoparticles. MB was supplied from Sigma-Aldrich. Sodium carbonate (Na₂CO₃), potassium dihydrogen phosphate (KH₂PO₄) and disodium hydrogen phosphate (Na₂HPO₄) supplied from Carlo Erba, Merck and VWR chemicals respectively were used to prepare a buffer solution for MB adsorption measurement. The antimicrobial activity was determined against Gram positive bacteria (*S. aureus, (ATCC 25923)*) which were purchased from Himedia Laboratories Put. Ltd., India.

Preparation of Ag-PAN-AC composite fibers

1.0 g of PAN and 0.64 g of AgNO₃ were admixed in 50 g of DMF and then stirred for 1 h at 60°C until yellow clear solution was obtained. 50.0 g of DMF containing 1.132 g of N_2H_5OH

was slowly added to the AgNO₃-PAN solution under magnetic stirring kept at 10°C in an ice bath. After that, 500 ml of acetone was added to the solution followed by filtering so that the free Ag nanoparticles were separated rapidly from the PAN-protected Ag nanoparticles (Ag-PAN nanoparticles)¹⁵. The latter part was dried in the vacuum oven overnight at 60°C. Ag-PAN-AC spinning solutions were prepared from 8 % (w/v) of Ag-PAN nanoparticles containing various AC concentrations of 0, 1, 2, 3, 4 and 5 % (w/v) in DMF. The mixtures were stirred at 60°C for 24 h prior to electrospinning. The dark-brown solution was held in a needle with the gap distance from the needle tip (diameter \cong 0.1 mm) to the rolling collector covered with aluminium foil (speed \cong 220 rounds min⁻¹ (rpm)) at about 30 cm under a voltage of 27 kV. The flow rate of spinning solution was 0.05 ml min⁻¹.

Characterization methods

The conductivity of spinning solutions was measured at 25°C before the electrospinning process using a waterproof multiparameter (pH/ conductivity/ TDS/ salinity/ temperature) tester (PCSTestr 35, Okaton Instruments, USA). The probe was immersed in 50 ml of spinning solution. The average conductivity of each sample from three measurements was recorded. The viscosity of spinning solutions was determined at 25°C by a viscometer (RT49427, Brookfield AMETEK, USA). 20 ml of spinning solution was filled in the cylinder and spun with the speed of 0-200 rpm. The average viscosity of each sample from three measurements was recorded. The surface morphologies of Ag-PAN-AC composite fibers were characterized using a Schottky field-emission scanning electron microscope (SEM, SU5000, Coax Group Corp. Ltd., Thailand). Prior to characterization, a sample on Al foil was attached onto an SEM stub using conducting tape and then sputter coated with a thin layer of platinum. The amount of Ag in Ag-PAN-AC composite fibers was determined using an X-ray fluorescence spectrometer (XRF PW2404, Philips, Thailand). All XRF analysis was performed using an X-ray beam collimator, an accelerating voltage of 30-60 kV, and an electron beam current of 66-125 mA.

Procedures for adsorption studies

The MB concentrations in the supernatant solutions before and after adsorption were determined using a UV-vis spectrometer (Lambda 950, PerkinElmer Co., Ltd., Thailand) at maximum wavelength (λ) of 664 nm. The MB concentration was calculated by comparing absorbance to a previously obtained calibration curve. A stock solution of 500 mg L⁻¹ was prepared by dissolving the appropriate amount of MB and completing the volume with buffer solution (pH = 7). Batch

adsorption was performed in a set of 100 mL glass bottles containing 50 mL of MB solution with various initial concentrations (10, 20, 30, 40 and 50 mg L⁻¹) to create a calibration curve. A composite fiber weight of 0.025 g at different AC concentrations was added to 50 mg L⁻¹ of MB solution and then kept at room temperature for 180 min. The amount of MB adsorbed onto composite fibers was calculated using equation (1):

MB adsorption (%) =
$$\left(\frac{(Co - Ce)}{Co}x100\right)$$

(1)

where C_o and C_e (mg L⁻¹) are the initial and equilibrium liquid-phase concentrations of MB respectively. All experiments were duplicated and only the mean values were reported.

The influences of the fiber content, MB concentration and adsorption duration on the MB adsorption capacity were also studied consecutively. The fiber weight was varied at 0.0125, 0.025, 0.050, 0.075 and 0.1 g while the AC content, MB concentration and adsorption duration were fixed at 5% (w/v), 50 mg L⁻¹ and 180 min respectively. The second step was to determine the MB adsorption at different MB concentrations at 10, 20, 30, 40 and 50 mg L⁻¹, while the suitable fiber weight was selected from the first step with the constant AC dosage and adsorption duration of 5% (w/v) and 180 min respectively. The last step was to study the MB adsorption at various adsorption durations of 180, 360, 540 and 720 min at constant AC content, fiber loading and MB concentration selected from the previous experiment.

For batch kinetic studies, the same procedure was followed but the aqueous samples were taken at preset time intervals. The concentrations of MB were also measured. The amount of MB adsorbed at any time, $q_t (mg g^{-1})$, was calculated from equation (2):

 $q_t = (C_0 - C_t) V/W$ (2)

where $C_t (mg L^{-1})$ is the liquid-phase concentration of MB at any time. Initial dye concentration of 10 mg L⁻¹ (C_0) and an adsorption time of 180, 360, 540 and 720 min were studied. V (L) is the volume of the solution, and W (g) is the mass of dry adsorbent.

Adsorption isotherm and kinetic models

The isotherms of two parameters, Langmuir and Freundlich¹⁹ were applied as shown in Table 1. Two kinetic models, pseudo-first order²² and pseudo-second order²³ were used to understand the adsorption dynamics in relation to time for the Ag-PAN-AC composite fiber-MB system. The equations and parameters of pseudo-first order and pseudo-second order are also presented in Table 1. Langmuir and Freundlich adsorption isotherms and kinetic models of pseudo-first and pseudo-second order were fitted employing a non-linear fitting method. The theoretical models properly describe the experimental data of MB-composite fiber system were chosen from the correlation coefficient (R^2).

Evaluation of bacterial activities

Antimicrobial activities were determined against Gram positive bacteria (*S. aureus, (ATCC 25923)*). The disc diffusion method²⁴ was carried out for determination of antimicrobial activity using 100 μ L suspensions containing 106 CFU/mL of bacteria spread on Mueller-Hinton agar (MHA) medium (Nutrient Agar (NA)). Muller-Hinton Agar was prepared from a commercially available dehydrated medium (Oxoid®) according to manufacturer's instructions. Three sterilized composite fiber samples with a diameter of 3.5 mm were placed on a disc (6 cm in diameter) containing the inoculated agar. The inhibition zone was measured after 24 h of incubation at 37°C. After incubation, the diameter of the clear zone around each disc plate was measured in millimeters and the value of mean was reported with \pm one standard deviation. The inhibition ratio was calculated from the ratio of clear zone diameter to negative control diameter.

Results and discussion

Spinning solution properties and Ag contents

The viscosity of spinning solutions tended to increase approximately from 45 to 54 Pa s when adding AC from 0 to 4% (w/v) then suddenly dropped to 36 Pa s at 5% (w/v) of AC as shown in Fig. 1 (a). The viscosity of spinning solution increased when the AC was added in the solution due to the dispersion of AC in the polymer matrix. However, the agglomeration of AC particles occurred at high AC concentration, causing the reduction of the solution viscosity.

The Ag concentration obtained from XRF analysis decreased from 11 to 4 % when the AC loading increased from 0 to 5 % (w/v) (see Fig. 1 (b)). This was due to the proportion of Ag-PAN nanoparticles to AC decreased with increasing AC content. The conductivity of spinning solution decreased from 540 to 139 μ S cm⁻¹ as the AC concentration increased from 0 to 5 % (w/v) because of the reduction of Ag-PAN nanoparticles to AC ratio, corresponding to the Ag

concentration results. In addition, AC has lower electrical conductivity than Ag in nature, therefore the conductivity of solution declined with increasing AC content.

Fiber morphology

The composite fibers had rough and porous surfaces due to some AC particles deposited on the fiber surfaces as depicted in Fig. 2 (a)-(f). The fiber diameter of composite fibers was insignificantly affected by the amount of AC. The average fiber diameter was approximately in the range of 200-250 nm. However, the bead fibers were obtained at high AC content because of low solution viscosity and the AC accumulation, causing difficulty in fiber stretching. For solution of low viscosities, surface tension is the dominant factor and just beads or beaded fibers are formed while above a critical viscosity, a continuous fibrous structure is obtained^{25, 26}. Ra et al. [27] also observed that beads formed especially when CNT concentration was high or the dispersion of the CNTs in solution was poor. Furthermore, lower elongation forces were imposed on the jet under the electrical field at high AC dosage, e.g. 4 and 5% (w/v), since the polymer solution had low electrical conductivity resulting in larger bead fibers. With the increase of electrical conductivity of the solution, there is a significant decrease in the diameter of the electrospun nanofibers whereas with low conductivity of the solution, there is insufficient elongation of a jet by electrical force to produce uniform fiber, and beads may also be observed¹.

MB adsorption

Fig. 3 (a) presents the MB adsorption of Ag-PAN-AC composite fibers at different AC contents. The MB adsorption increased with the increment of AC loadings and this could be attributed to higher availability of more adsorption sites. The composite fibers containing 5% (w/v) of AC gave the maximum MB adsorption capacity of about 25% with the fiber weight of 0.025g, MB concentration of 50 mg L⁻¹ and the adsorption duration of 3 h. The fiber weight also affected the MB adsorption while the composition of fibers, MB concentration, and adsorption time were kept constant as shown in Fig. 3 (b). The MB adsorption tended to increase as the fiber weight increased due to the high amount of AC content and high surface area of fibers. Along with the adsorbent dosage increased from 0.0125 to 0.1 g, the MB adsorption increased from 20 to 60% as a result of higher availability of more adsorption sites. At the same fiber weight and adsorption duration of composite fibers containing 5% (w/v) of AC, the MB adsorption had a

tendency to decrease then level off to a constant value at MB concentration of 30 ppm onward (see Fig. 3 (c)). At constant fiber loading and higher initial dye concentrations, the available adsorption sites of adsorbent became fewer, thus a decrease in the removal efficiency occurred. Figure 3 (d) presents the MB adsorption of 0.1 g of composite fibers containing 5% (w/v) of AC at MB concentration of 10 ppm. As shown, there was a rapid uptake in the first 9 h, afterwards a plateau was reached. The maximum dye adsorption was obtained at approximately 95% for adsorption duration of 9 h. The adsorption parameters such as AC content, fiber weight, MB concentration, and adsorption time could be optimized to obtain high adsorption capacity with economical balance.

Adsorption isotherm

In order to optimize the design of an adsorption system of Ag-PAN-AC composite fibers containing 5% (w/v) of AC, two adsorption isotherm models namely Langmuir and Freundlich in their linear forms were applied to the equilibrium data and are shown in Fig. 4 (a)-(b), respectively. The Langmuir and Freundlich isotherms are known as two-parameter models, which provide information on the adsorption capacity and constants related to the activation energy. The values of the maximum adsorption capacity (q_m) , correlation coefficient (R^2) and other constants obtained for the models from experimental data are shown in Table 2. The Langmuir model assumes that the adsorption is a process which occurs in a homogeneous surface, in which the molecules form a monolayer of adsorbate on the surface of the material, saturating the pores and preventing the transmigration²⁸. According to the results presented in Table 2, the q_m and R^2 values obtained from Langmuir isotherms were 49.26 mg g⁻¹ and 0.963, respectively. The q_m of 49.26 mg g⁻¹ was close to the experimental value which was about 57.80 mg g⁻¹. The separation factor (R_L) defined by Weber and Chakkravorti²⁹ is an important parameter of the Langmuir isotherm that can be used to verify if the adsorption in the system is unfavorable ($R_L > 1$), linear ($R_L = 1$), favorable ($0 < R_L < 1$) or irreversible ($R_L = 0$). The R_L values was approximately of 0.39, indicating that the composite fibers containing 5% (w/v) of AC system was favorable.

The Freundlich model is an empirical equation based on the adsorption on heterogeneous surface²⁸. The heterogeneity factor (n_F) indicates whether the adsorption process is linear (n_F = 1), chemical (n_F < 1) and or physical (n_F > 1). Additionally, the value of $1/n_F < 1$ indicates a normal Langmuir isotherm while $1/n_F > 1$ is an indicative of cooperative adsorption^{19, 21}. According to the results shown in Table 2, the values of n_F = 1.29 and $1/n_F = 0.78$ indicated that the adsorption

was physical, and that the experimental data fitted preferentially the Langmuir isotherm. The R^2 value for the Freundlich model was 0.902. Comparing the R^2 values in Table 2, it can be observed that the Langmuir model yielded the best fit with the higher R^2 value. The suitability of the Langmuir model to experimental data was confirmed by the value of $1/n_F$ described by the Freundlich model. The fit of the experimental data to the Langmuir model indicated a homogeneous nature of the composite fibers containing 5% (w/v) of AC surface. Additionally, it described the formation of monolayer coverage of dye molecules at the outer surface of the composite fibers.

Kinetic studies

Kinetic studies are important to understand the dynamic of the reaction in terms of order of the rate constant. The data of adsorption kinetics for the Ag-PAN-AC composite fibers containing 5% (w/v) of AC system using the solution at initial MB concentration of 10 mg L⁻¹ were analyzed by linear fitting of two different kinetic models: pseudo-first order and pseudo-second order, shown in Fig. 5 and Fig. 6 (a)-(b). Table 3 shows the parameters obtained from the fits of the adsorption kinetic models. The correlation coefficients (R²) for composite fibers containing 5% (w/v) of AC were 0.1975 for pseudo-first order model and 0.9730 for pseudo-second order model. The highest values of R² were observed in the pseudo-second kinetic model. Additionally, the qe value (5.7 mg g⁻¹) obtained by data fitting of the pseudo-second order model was also close to the q_{exp} value (4.7 mg g⁻¹). This suggests that the rate of the adsorption process was preferably controlled by chemisorption. This was in agreement with a report by Aluigi et al.³⁰, which studied the MB adsorption on keratin nanofibrous membranes.

Antibacterial activity

Antibacterial properties of Ag-PAN nanofibers loaded AC particles were tested on *S. aureus* (gram-positive) microorganisms. Ag-PAN nanofibers and Ag-PAN-AC composite fibers exhibited the absence of colony-forming units (clear zone) on the plates, suggesting partial inhibition zone against *S. aureus* as shown in Fig. 7 (b)-(g). For comparison, results of neat PAN nanofibers used as a control sample (Fig. 7 (a)) showed no antibacterial activity against *S. aureus* because the clear zone did not appear on the plate. The formation of clear zone of inhibition around composite fiber samples obviously indicated that the Ag⁺ ions were effective on the inhibition of bacterial growth since they attached to the cell walls and disturb cell-wall permeability and cellular respiration³¹. Moreover, nano-sized fibrous membranes also provided

relatively larger surface areas to contact with bacteria³². The efficiency of antibacterial activity of *S. aureus* increased as the percentage of AC particles in composite fibers increased since the zone of inhibition defined as the inhibition ratio increased from 2 to 3.29 with the increase of AC contents from 0 to 5% (w/v) as shown in Fig. 8. This implied that AC particles had synergetic effects on antibacterial activity against *S. aureus*.

Conclusions

In this work, Ag-PAN-AC composite fibers possessed rough and porous surfaces with a mean diameter of about 200-250 nm. The fiber diameter insignificantly decreased with increasing bead fibers as the AC loading increased. The composite fibers containing 5% (w/v) of AC exhibited the maximum MB adsorption capacity (~ 95%) at MB concentration of 10 ppm, fiber content of 0.1 g, and adsorption time of 9 h. The adsorption parameters such as initial dye concentration, fiber content, AC dosage and time might be adjusted to obtain suitable conditions for maximum MB adsorption. The adsorption results indicated that the Langmuir isotherm fitted the experimental data better than the Freundlich isotherm models. This suggested that the adsorption process occurred on a homogeneous surface, in which the molecules formed a monolayer of adsorbate on the surface of the material. The kinetic data were found to fit the pseudo-second order model better than the pseudo-first order model, indicating that the adsorption of MB on composite fibers was a chemisorption process. The composite fibers containing 5% (w/v) of AC gave the highest inhibition zone against S. aureus, indicating the synergetic effect of AC and high surface area fibers on antimicrobial activity. The combination of high specific surface area and fineness of fibers with the biocidal activity of Ag nanoparticles and high adsorption capacity of AC resulted in the possibility of using Ag-PAN-AC composite fibers as a bifunctional material in chemical adsorption with antibacterial activity. Furthermore, the composite fibers feasibly separated from dye solution and showed high recyclable removal efficiency.

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Fig. 1—Viscosities of spinning solutions having different AC contents (a) and conductivities of spinning solutions and Ag concentrations of Ag-PAN-AC composite fibers at different AC contents (b)



Fig. 2 — SEM micrographs of Ag-PAN-AC composite fibers at various AC loadings (% (w/v)): (a) 0, (b) 1, (c) 2, (d) 3, (e) 4, and (f) 5





Fig. 3 — MB adsorption behaviors of Ag-PAN-AC composite fibers at different AC contents (a), fiber weights (b), MB concentrations (c), and adsorption times (d)



Fig. 4 — Linear fits of the isotherm models from MB adsorption of Ag-PAN-AC composite fibers containing 5% (w/v) of AC at MB concentration of 10 mg L^{-1} : (a) Langmuir and (b) Freundlich



Fig. 5 — MB adsorption capacity versus adsorption time curve for Ag-PAN-AC composite fibers containing 5% (w/v) of AC at MB concentration of 10 mg L^{-1}



Fig. 6 — Linear fits of pseudo-first order (a) and pseudo-second order (b) kinetics for Ag-PAN-AC composite fibers containing 5% (w/v) of AC at MB concentration of 10 mg L^{-1}



Fig. 7 — Antibacterial test plates of *S. aureus* using Ag-PAN-AC composite fibers at various AC loadings (% (w/v)): (a) PAN fibers (control), (b) 0 (Ag-PAN Nanofibers), (c) 1, (d) 2, (e) 3, (f) 4, and (g) 5



Fig. 8 — Inhibition ratios against *S. Aureus* of Ag-PAN-AC composite fibers at different AC concentrations (% (w/v)): (a) PAN fibers (control), (b) 0 (Ag-PAN Nanofibers), (c) 1, (d) 2, (e) 3, (f) 4, and (g) 5

Table 1 — Non-linear forms of isotherm and kinetic models.

Models	Names	Expressions
Isotherm	Langmuir	$q_e = \frac{Q_m K_a C_e}{1 + K_a C_e}$
	Freundlich	$R_L = \frac{1}{1 + K_a C_e}$
		$q_e = K_F C_e^{1/n_F}$
Kinetic	Pseudo-first order	$q_t = q_e [1 - e^{-K_1 t}]$
		$h_0 = K_1 q_e$
	Pseudo-second order	$q_t = \frac{K_2 q_e^2 t}{1 + K_2 q_e t}$
		$h_0 = K_2 q_e^2$

 Q_m = the maximum adsorption capacity; K_a = the Langmuir constant; R_L = the separation factor; K_F and n_F = Freundlich constants; q_e = the amount of MB adsorbed onto ECFs at equilibrium (mg g⁻¹); q_t = the amount of MB adsorbed at any time (mg g⁻¹), K_1 and K_2 = rate constants for the pseudo-first and pseudo-second order models, respectively; h_0 = the initial adsorption rate, t = time (min)

Table 2 — Langmuir and Freundlich isotherm parameters and correlation coefficients for MB adsorption on Ag-PAN-AC composite fibers containing 5% (w/v) of AC

Model	Isotherm parameters				
Langmuir	$q_m (mg g^{-1})$	$K_A(L mg^{-1})$	R ²	R _L	
	49.26	0.031	0.963	0.39	
Freundlich	$K_F(mg g^{-1})$	n _F	R ²	-	
	1.04	1.29	0.902	-	

Table 3 — Pseudo-first order and pseudo-second order kinetic model parameters for MB concentration of 10 mg L^{-1} on Ag-PAN-AC composite fibers containing 5% (w/v) of AC

C ₀ (mg L ⁻¹)	$q_{e,exp}$ (mg g ⁻¹)	Pseudo-first order	Pseudo-second order
10	4.7	$q_e = 1.5 (mg g^{-1})$	$q_e = 5.7 (mg g^{-1})$
		$K_1 = 7.0 \times 10^{-4} (min^{-1})$	$K_2 = 1.1 \times 10^{-3} (min^{-1})$
		$h_0 = 1.05 \text{ x } 10^{-3} \text{ (mg g}^{-1} \text{ min}^{-1}\text{)}$	$h_0 = 6.27 \text{ x } 10^{-3} \text{ (mg g}^{-1} \text{ min}^{-1}$
		$R^2 = 0.1975$	¹)
			$R^2 = 0.9730$