KINETICS OF GASEOUS TOLUENE ADSORPTION ON CANDLENUT SHELL ACTIVATED CARBON

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ABSTRACT

Adsorption kinetics of gaseous toluene on activated carbon prepared from candlenut shell had been studied. The research was performed by examining adsorption data, which was obtained in previous research, over several rate equations, which were: (1) Lagergren's pseudo first order rate equation, (2) Ho's pseudo second order rate equation, (3) Elovich's equation, and (4) persamaan Ritchie's equation. The result showed that the data of toluene adsorption on candlenut shell activated carbon fits the Ho's pseudo second order rate equation and, hence, the model is the most applicable model for the adsorption. Calculation from linear regression of Ho's pseudo second order rate equation gave the equilibrium adsorption capacity value of 56,069 mg g^{-1}, second order rate constant of $3{,}54 \times 10^{-4}$ g mg^{-1} min^{-1}, and initial adsorption rate of 1,112 mg g^{-1} min^{-1}.

Keywords: adsorption, candlenut, activated carbon, toluene

KINETIKA ADSORPSI GAS TOLUENA PADA KARON AKTIF TEMPURUNG KEMIRI

ABSTRAK

Studi mengenai aspek kinetika adsorpsi toluena pada arang aktif yang terbuat dari tempurung kemiri telah dilakukan. Penelitian dilakukan dengan menguji data adsorpsi yang telah diperoleh pada penelitian terdahulu menggunakan empat persamaan laju adsorpsi, yaitu (1) persamaan laju pseudo order pertama Lagergren, (2) persamaan laju pseudo order kedua Ho, (3) persamaan Elovich, dan (4) persamaan Ritchie. Hasil kajian menunjukkan bahwa model kinetika dengan persamaan laju pseudo order kedua Ho adalah yang paling sesuai diaplikasikan untuk adsorpsi gas toluena pada arang aktif tempurung kemiri. Dari persamaan linear untuk model kinetika pseudo order kedua Ho diperoleh nilai kapasitas adsorpsi pada kesetimbangan sebesar 56,069 mg g^{-1}, konstanta adsorpsi sebesar $3{,}54 \times 10^{-4}$ g mg^{-1} $menit^{-1}$, dan laju adsorpsi awal sebesar 1,112 mg g^{-1} $menit^{-1}$.

Kata kunci: adsorpsi, kemiri, karbon aktif, toluena

INTRODUCTION

Adsorption kinetics is one of the aspects investigated in evaluating characteristics of an adsorbent applied especially for environmental remediation. Several models of adsorption kinetics have been developed in order to estimate the rate with which an adsorbent removes substances from the system. Some of the models have been reviewed by Qiu *et al*. (2009) and Ho (2006), those are : (1) Lagergren's pseudo first order rate equation that has been applied in describing the adsorption characteristics of pollutants from wastewater, (2) Ho's pseudo second order rate equation that has been applied successfully in characterizing the adsorption of metal ions and organic substances from aqueous solutions, (3) Elovich's equation which is applied mainly in the adsorption of gas onto solid systems, and (4) Ritchie's equation which is widely used also in gas-solid systems.

In this research, these rate equations were evaluated in order to describe the adsorption of gaseous toluene on activated charcoal prepared from candlenut (*Aleurites mollucana*) shell. In previous research (Bukasa *et al*., 2012), it was found that this material has adsorption capacity of 0.094 cm^3/g for gaseous toluene and the adsorption equilibrium was reached in 300 minutes. The adsorption data obtained in the previous research was used in the calculation using the four rate equations to meet the model most applicable for the adsorption of toluene on candlenut shell activated carbon.

METHODOLOGY

Preparation of candlenut shell activated carbon and experiment of toluene adsorption on the adsorbent was described in the previous article (Bukasa *et al.*, 2012). Adsorption data in terms of the time required to reach adsorption equilibrium state was used to evaluate rate equation most applicable for this adsorption. Rate equations evaluated in this research were:

(1) Pseudo first order rate equation

This rate equation is presented as:

$$\log(q_e - q_t) = \log q_e - \left(\frac{k}{2.303}\right)t$$

where q_e is the adsorption capacity at equilibrium, q_t is the adsorption capacities at time *t*, and k is the pseudo first order rate constant. Plot of $\log(q_e - q_t)$ versus time *t* would give a straight line and the coefficient of determination, R^2, could be revealed.

(2) Ho's Pseudo second order rate equation which is expressed in the form:

$$\frac{t}{q_t} = \frac{1}{V_0} + \frac{1}{q_e}t$$

where V_0 is initial adsorption rate which equals to pseudo second order rate constant multiplied by q_e^2. Plot of t/q_t versus *t* should result in a straight line and its corresponding coefficient of determination R^2.

(3) Elovich's equation

Elovich's equation is widely used to elucidate the adsorption of gas particles onto solid systems and has the expression of:

$$q = \alpha \ln(a\alpha) + \alpha \ln t$$

where *q* is the amount of gas adsorbed at time *t*, α is desorption constant, and *a* is initial adsorption rate. A straight line and its corresponding R^2 should be obtained by plotting *q* against ln *t*.

(4) Ritchie's equation

Ritchie's equation is also widely used in the adsorption of gas particles onto solid systems. The expression of this equation is :

$$\frac{q_\infty}{q_\infty - q} = \alpha t + 1$$

where *q* and q_∞ are the amount of gas adsorbed at time *t* and after an infinite time, respectively, and α is the rate constant. This equation is simply a linear equation and plot of $q_\infty/(q_\infty - q)$ *versus t* would produce a straight line.

Given that the value of coefficient of determination R^2 describes how well a regression line fits a set of data, the rate equation that has highest value of R^2 should be the best expression to be applied for the adsorption of toluene on candlenut shell activated carbon. Adsorption data used in the evaluation of adsorption kinetics is shown in Table 1.

Table 1. Adsorption data of toluene on candlenut activated carbon (after Bukasa et al., 2012)

time (min)	mass of activated carbon (g)	mass of adsorbed toluene (g)
60	10.0054	0.3559
120	10.0069	0.3861
180	10.0078	0.4448
240	10.0035	0.4904
300	10.0072	0.5206
600	10.0049	0.4710
1080	10.0054	0.5146
1440	10.0058	0.5620

RESULTS AND DISCUSSION

The linear regression analysis of adsorption data in relation to pseudo first order rate equation, pseudo second order rate equation, Elovich's equation, and Ritchie's equation are displayed in Figure 1, 2, 3, and 4 respectively.

It is obviously noticed that the linear regression analysis with respect to Ho's pseudo second order rate equation generates a straight line that best fit to the data of adsorption of gaseous toluene on candlenut shell activated carbon. It, unexpectedly, does not fit the Elovich's or Ritchie's equation which are widely used in describing the adsorption of gaseous particles on solid systems. The coefficients of determinations are 0.994, 0.784, 0.405, and 0.254 for pseudo second order, Elovich's, pseudo first order, and Ritchie's equation.

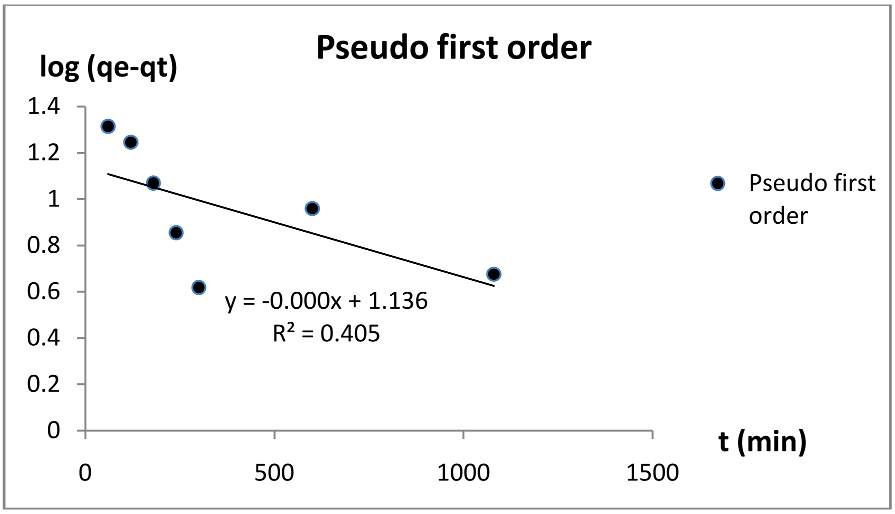

Figure 1. Plot of log(q_e-q_t) *vs*. t and its corresponding R^2 according to pseudo first order rate equation

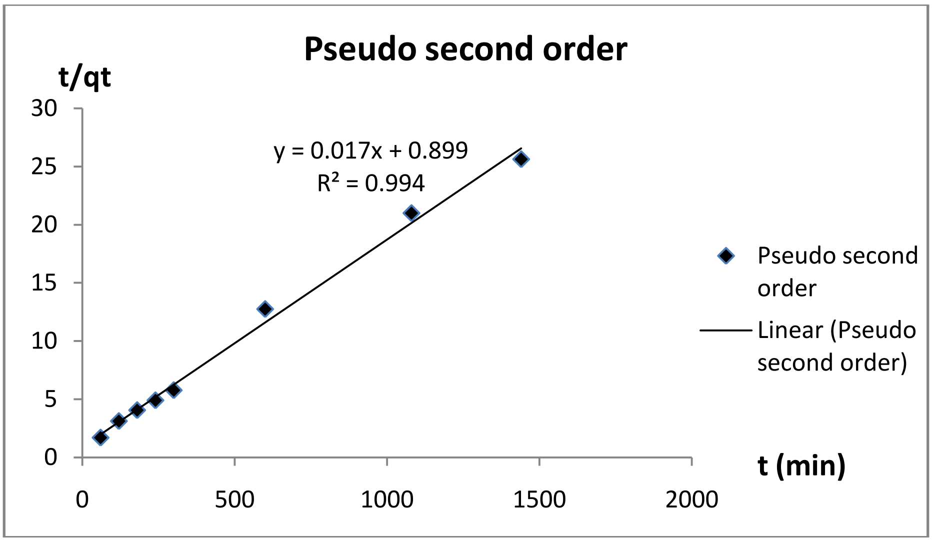

Figure 2. Plot of t/q_t *vs*. t and its corresponding R^2 according to pseudo second order rate equation

Pseudo second order has been succesfully applied to the adsorption of metal ions, dyes, herbicides, oils, and organic substances from aqueous solutions (Ho, 2006). Indeed, Ho's pseudo second order equation, developed based on the adsorption capacity on the solid phase, is claimed to have ability in predicting the behavior above the whole range of analysis involving a pseudo second order equation and it confirms chemisorption as the rate controlling step (Ho and McKay, 1998). However, Bukasa *et al*. (2012) found that the adsorption energy involved in adsorption of toluene on the candlenut shell activated carbon implies that it is a physical adsorption. This might be resulted from the calculation of adsorption energy using Dubinin-Raduskevich (DR) equation which is based on the Theory of Volume Filling of Micropores (TVFM).

In TVFM, particles are not adsorbed to form layers but through volume filling of micropores which results in lower energy of adsorption. This model is different from the description of Ho's pseudo second order equation which is based on the adsorption of divalent metals on moss peat. The assumption is that the divalent metal ions are adsorbed chemically through sharing or exchange of electrons between the metal ions and peat (Ho, 2006). The difference is evident as the adsorption capacity of 81.78 mg g^{-1} (equivalent to 0.094 cm^3 g^{-1}) resulted from Dubinin-Raduskevich equation (Bukasa *et al*, 2012) is compared to that of 56.069 mg g^{-1} resulted from Ho's pseudo second order rate equation. Volume filling of activated carbon micropores results in much higher adsorption capacity which is much weaker in energy of adsorption.

Using Ho's pseudo second order rate equation, the second order rate constant k and initial adsorption rate could be determined. In this case, the rate constant k is $3.54x10^{-4}$ g mg^{-1} min^{-1} and initial adsorption rate V_0 is 1.112 mg g^{-1} $menit^{-1}$.

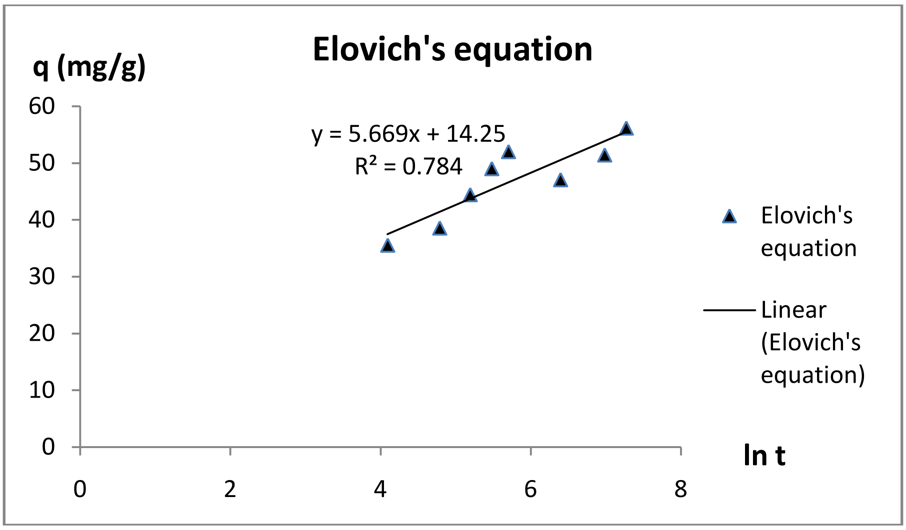

Figure 3. Plot of *q vs.* ln t and its corresponding R^2 according to Elovich's equation

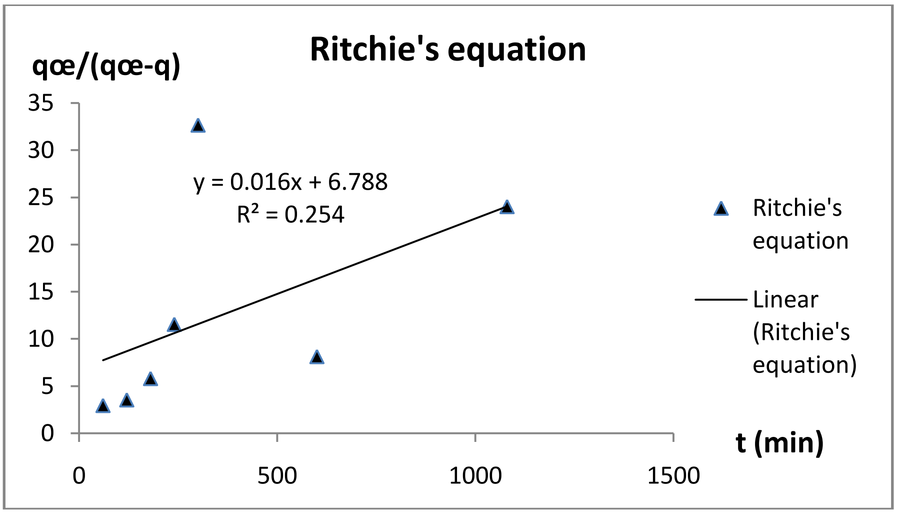

Figure 4. Plot of $q_\infty/(q_\infty - q)$ *vs.* ln *t* and its corresponding R^2 according to Rirchie's equation

CONCLUSION

The adsorption data of gaseous toluene on activated carbon prepared from candlenut shell fits the Ho's pseudo second order rate equation. This kinetic model confirms the chemical adsorption involved as the rate controlling step despite the data of adsorption energy which validates the involvement of physical adsorption of toluene on candlenut shell activated carbon. However, different assumptions used in different equations in calculating the two parameters could be the source of this inconsistency.

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