CHAPTER 3

RESULTS AND DISCUSSION

3.1 Construction of the aflatoxin B_1 calibration curves

In order to determine the amounts of aflatoxin B_1 concentrations left in all studied solutions, the calibration curve of standard aflatoxin B_1 solutions was established by plotting the aflatoxin B_1 concentration (mol/L) (x-axis) against the absorbance (y-axis). In this work, the standard aflatoxin B_1 solutions with concentrations ranging from 0.50 to 8.00 ppm were employed for constructing a calibration curve. Each standard aflatoxin B_1 solution was measured by using UV–VIS spectrophotometry for absorbance at a wavelength of 362 nm. Figure 3.1 and Table 3.1 presented the calibration curve and the adsorption data of aflatoxin B_1 adsorption at 25 ^{o}C.

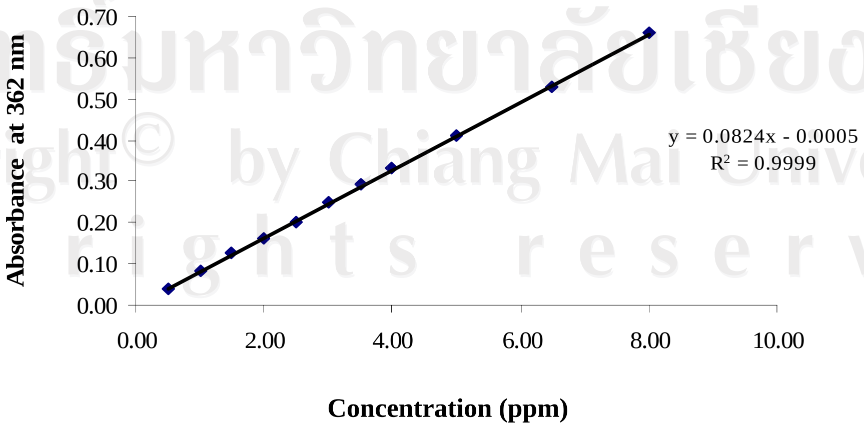

Figure 3.1 Calibration curve of the standard aflatoxin B_1 solution at 25 ^{o}C

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Table 3.1 Absorbance at 362 nm obtained from a series of standard aflatoxin B_1 solutions at 25 ^oC

Aflatoxin B_1 Concentration (ppm)	Absorbance (A_{362})				
	1	**2**	**3**	**average**	**S.D[a]**
0.50	0.0384	0.0401	0.0404	0.0396	0.0011
1.00	0.0797	0.0822	0.0823	0.0814	0.0015
1.50	0.1244	0.1255	0.1253	0.1251	0.0006
2.00	0.1622	0.1636	0.1641	0.1633	0.0010
2.50	0.1995	0.2023	0.2028	0.2015	0.0018
3.00	0.2456	0.2483	0.2491	0.2477	0.0018
3.50	0.2902	0.2932	0.2918	0.2917	0.0015
4.00	0.3306	0.3311	0.3309	0.3309	0.0003
5.00	0.4064	0.4136	0.4141	0.4114	0.0043
6.50	0.5274	0.5326	0.5342	0.5314	0.0036
8.00	0.6541	0.6619	0.6621	0.6594	0.0046

[a] S.D: standard deviation

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3.2 Study of adsorption isotherms

In this work, different adsorbents consisting of the commercial toxin binder, the commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite were examined for adsorption of aflatoxin B_1 *in vitro*. Adsorption isotherms were obtained by plotting the adsorbed aflatoxin B_1 versus the concentration of aflatoxin B_1 at equilibrium. The data represented the mean adsorption of aflatoxin B_1 onto the adsorbent from three replicate experiments. Adsorption isotherms of aflatoxin B_1 onto six adsorbents at 25 ^{o}C were shown in Figure 3.2.

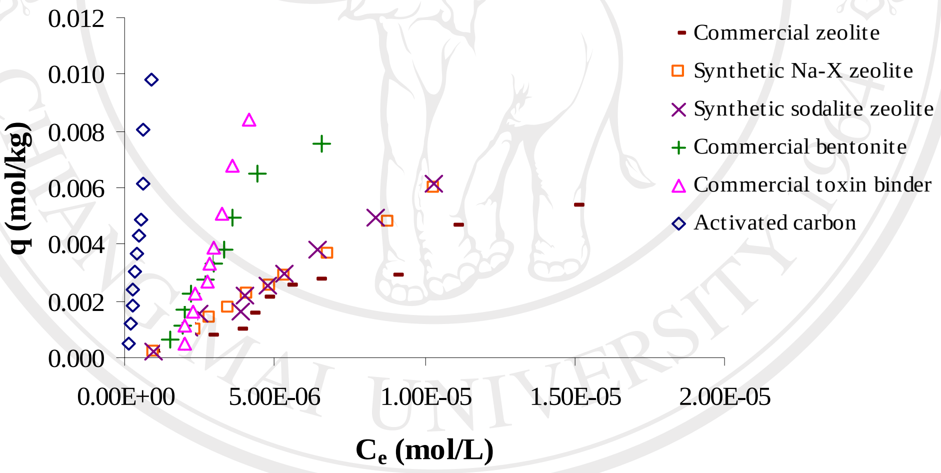

Figure 3.2 Adsorption isotherms for aflatoxin B_1 on six adsorbents at 25 ^{o}C

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These isotherm plots in Figure 3.2 presented that the adsorption behaviors of aflatoxin B_1 on different materials including the commercial toxin binder, the commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite as a function of increasing aqueous aflatoxin B_1 concentrations after equilibration for 24 hr. The extent of adsorption increased with the initial concentration increased from 0.50 to 8.00 ppm. Overall, the adsorption behaviors of aflatoxin B_1 were similar, with difference in the amounts adsorbed. However, aflatoxin B_1 seems to prefer activated carbon for its fastest adsorption.

The linearized Langmuir and Freundlich isotherm models were applied to characterize the adsorption behavior, and estimate values of the adsorption capacity and affinity constants of each adsorbent. The Langmuir model is a simple model based on monolayer adsorption onto a surface. While the Freundlich model is an empirical equation, which used for the description of multilayer adsorption with interaction between adsorbed molecules, and applies to adsorption onto heterogeneous surfaces with a uniform energy distribution and reversible adsorption [60]. The Langmuir constants were calculated from the plots of C_e/q versus C_e. The Freundlich constants, the adsorption capacity (K_f) and the affinity constant (n^f), were obtained from the linear plot of *log q* against *log* C_e. The intercept of the line was an indicator of the adsorption capacity, and the slope was an indication of the affinity constant.

The linearized Freundlich and Langmuir plot for aflatoxin B_1 adsorption onto the commercial toxin binder, the commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite and synthetic sodalite zeolite could be seen in Figure 3.3 and 3.4, respectively. The comparison of fitting characteristics achieved from two linearized isotherm models for six adsorbent materials at 25 ^{o}C were also shown in Table 3.2.

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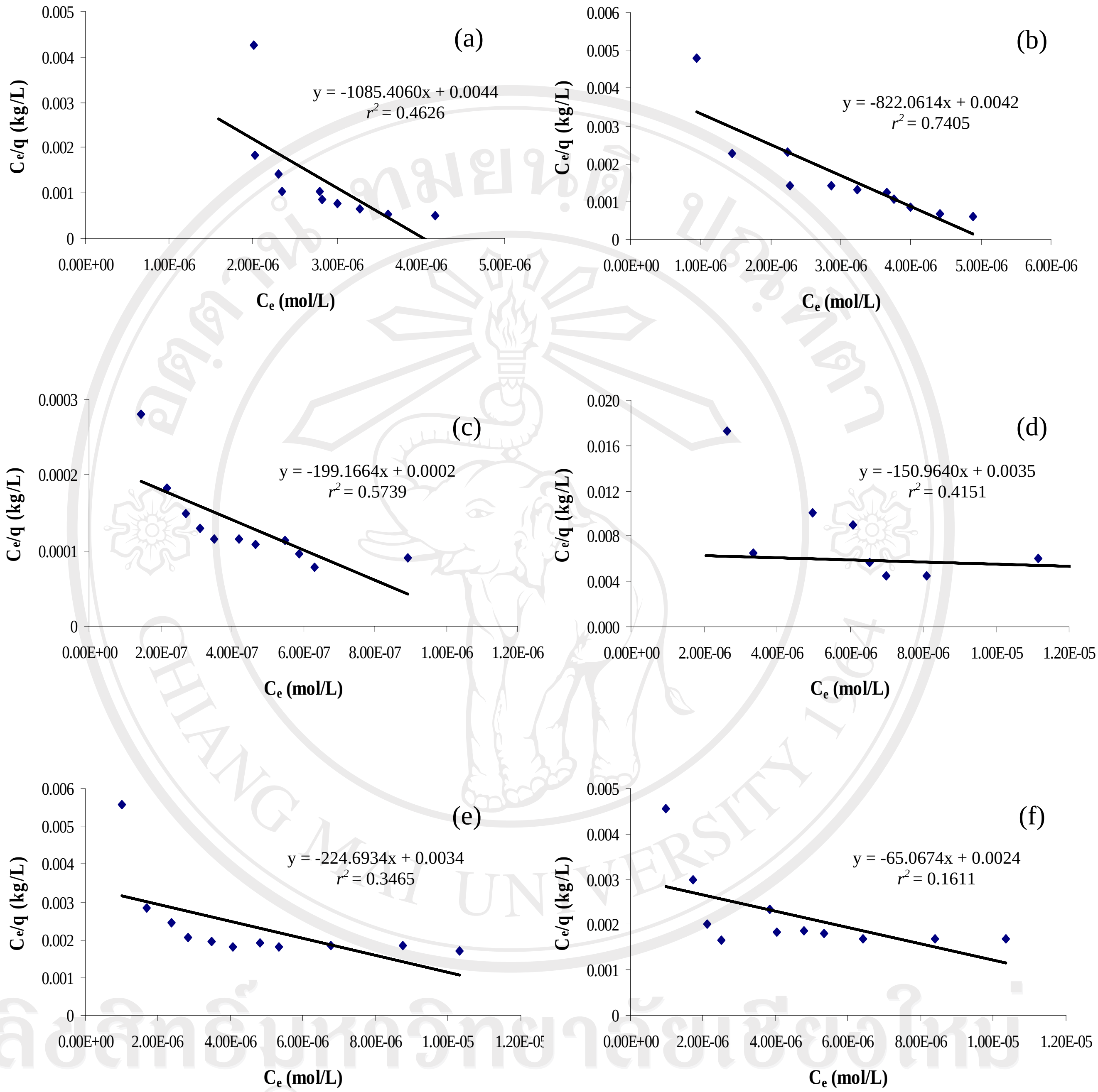

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Figure 3.3 The linearized Langmuir plots for aflatoxin B_1 adsorption onto: (a) the commercial toxin binder, (b) the commercial bentonite, (c) activated carbon, (d) the commercial zeolite, (e) synthetic Na-X zeolite and (f) synthetic sodalite zeolite at 25 ^oC

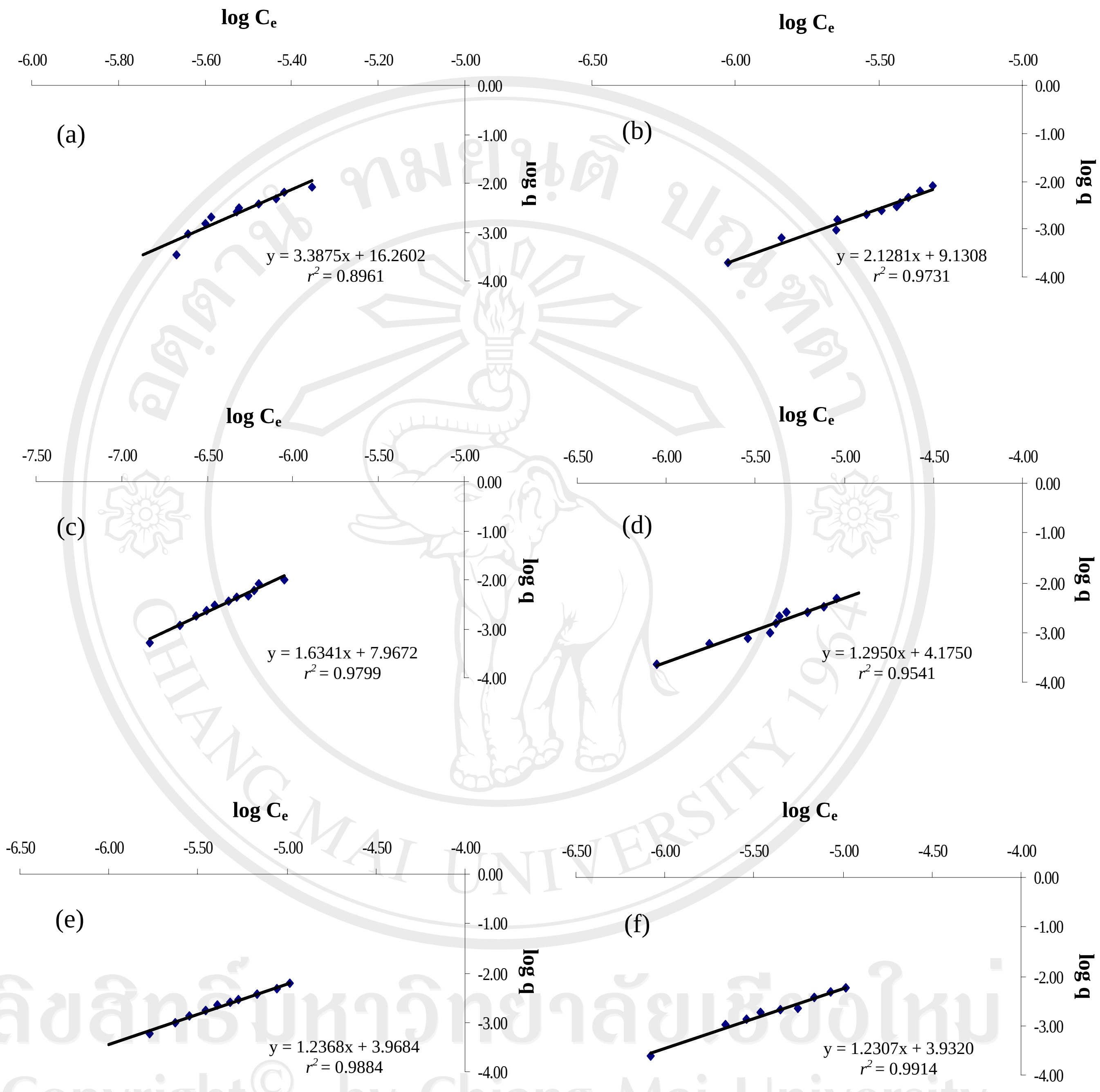

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Figure 3.4 The linearized Freundlich plots for aflatoxin B_1 adsorption onto: (a) the commercial toxin binder, (b) the commercial bentonite, (c) activated carbon, (d) the commercial zeolite, (e) synthetic Na-X zeolite and (f) synthetic sodalite zeolite at 25 ^oC

Table 3.2 Comparison fitting characteristics of isotherm data obtained from the linearized Langmuir and Freundlich models at 25 ^{o}C

Adsorbent	LM	FM		
	r^2	r^2	n^f	K_f
Commercial toxin binder	0.4626	0.8961	3.39	1.82×10^{16}
Commercial bentonite	0.7405	0.9731	2.12	1.35×10^{9}
Activated carbon	0.5739	0.9799	1.63	9.27×10^{7}
Commercial zeolite	0.4151	0.9541	1.30	1.50×10^{4}
Synthetic Na-X zeolite	0.3465	0.9884	1.24	9.30×10^{3}
Synthetic sodalite zeolite	0.1611	0.9914	1.23	8.55×10^{3}

LM is linearized Langmuir model, FM is linearized Freundlich model.

The results in Table 3.2 revealed that the Freundlich model presented the better fitted of experimental data than the Langmuir model, as indicating from the high values of correlation coefficients (r^2). This implied that the adsorption behavior of aflatoxin B_1 on these adsorbents were multilayer/multiple site adsorption on heterogeneous surfaces. The adsorption was not limited to a monomolecular layer, but could continue until a multimolecular layer of liquid covers the adsorbent surface [41].

The value of Freundlich's constant can be correlated and predicted to the adsorption capability of the adsorbent. From the experimental results, it could be simply understood that the commercial toxin binder had the highest adsorption capacity among the studied adsorbents. The adsorption capacity of the commercial toxin binder was around 1.82×10^{16} mol/kg. Obviously, this value was much higher

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than the adsorption capacities of some other adsorbent materials for aflatoxin B_1, which the adsorption capacities of the commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite and synthetic sodalite zeolite were around 1.35×10^9, 9.27×10^7, 1.50×10^4, 9.30×10^3, 8.55×10^3 mol/kg, respectively. The affinity constants for the commercial toxin binder, the commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite and synthetic sodalite zeolite were 3.39, 2.12, 1.63, 1.30, 1.24, and 1.23, respectively. From the values of adsorption capacity and affinity constants, it was found that the commercial toxin binder was highly effective for adsorption aflatoxin B_1 from aqueous solution, followed by the commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite and synthetic sodalite zeolite, respectively.

3.3 Study on the temperature effect

In order to understand the nature of adsorption occurring on the surface of adsorbent materials, adsorption isotherm at different temperatures was aimed for a study. The experiments were carried out at three different temperatures: 25, 37, and 45 ^{o}C. The aflatoxin B_1 concentration left in the solutions was measured by using UV-VIS spectrophotometer at a wavelength of 362 nm. The data from isothermal analysis were calculated and plotted as the amount of aflatoxin B_1 adsorbed (q) versus the aflatoxin B_1 concentration (C_e). Adsorption isotherms of aflatoxin B_1 on the commercial toxin binder, the commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite at 25, 37 and 45 ^{o}C demonstrated in Figure 3.5 (a)-(f), respectively.

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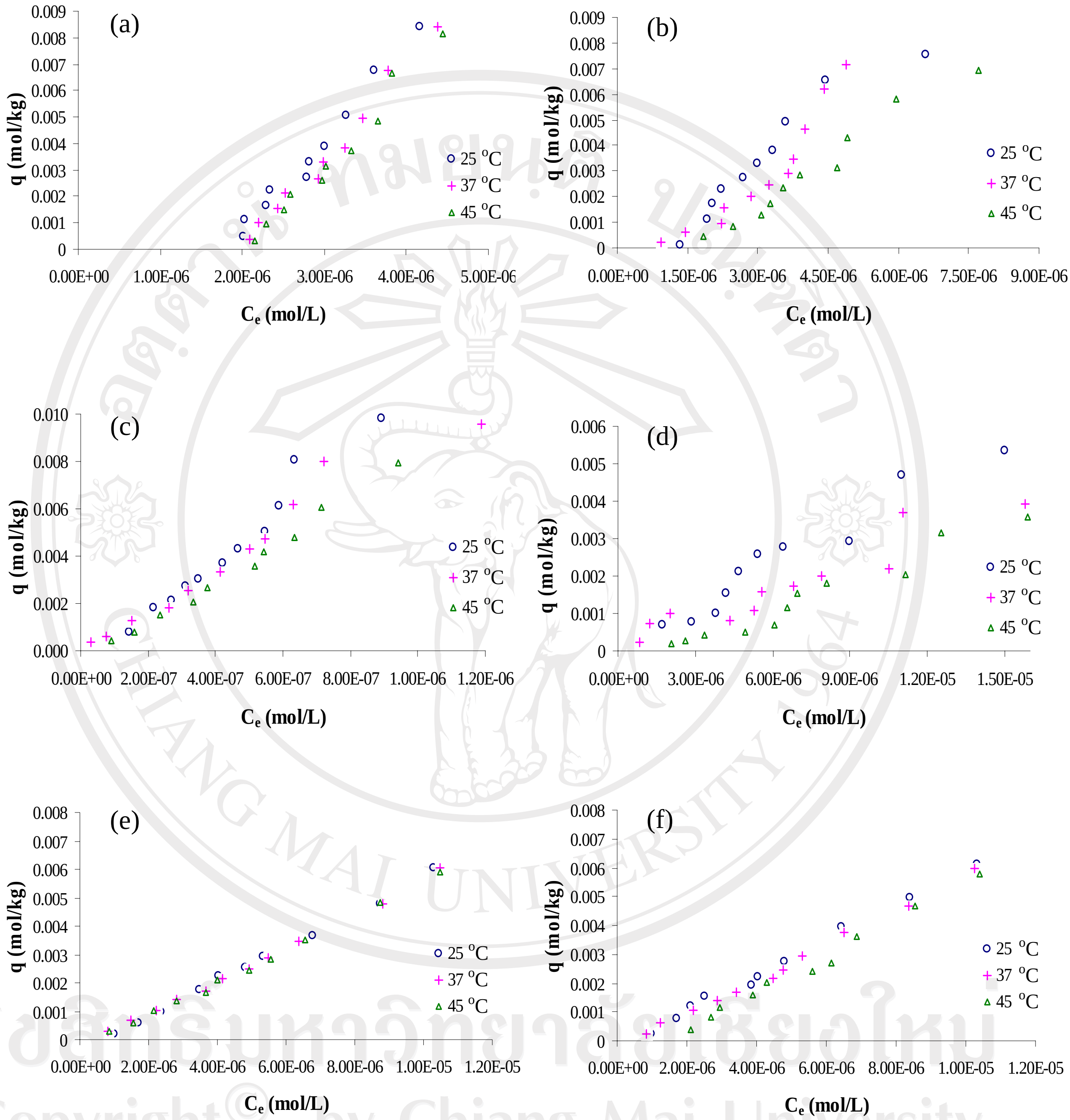

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Figure 3.5 Adsorption isotherms of aflatoxin B_1 onto: (a) the commercial toxin binder, (b) the commercial bentonite, (c) activated carbon, (d) the commercial zeolite, (e) synthetic Na-X zeolite and (f) synthetic sodalite zeolite at different temperatures

From Figure 3.5 (a)-(f), it was found that the adsorbed amount of aflatoxin B_1 slightly decreased when temperature increased from 25 to 45 ^oC. They also explained that the exothermic adsorption nature of the adsorption process. The temperature change had slightly affected the adsorption behaviors of aflatoxin B_1 on the commercial toxin binder, activated carbon and synthetic sodalite zeolite. This implied that the high degree of chemical interaction occurred for these adsorbents. On the other hand, the temperature change had no significant effect on aflatoxin B_1 adsorption by synthetic Na-X zeolite. The commercial bentonite and the commercial zeolite were more sensitive to temperature change than other adsorbents. That means physisorption interaction might play an important role. Normally physisorption are more sensitive to temperature change than chemisorption. Overall, the highest degree of adsorption aflatoxin B_1 obtained at 25 ^oC.

The linearized models, namely linearized Langmuir and Freundlich isotherms were used to fit the experimental data to obtain the values of the adsorption capacity and affinity constants of all adsorbents. The linearized Langmuir and Freundlich fitting characteristics of isotherm data at different temperatures were summarized and presented in Table 3.3.

The results in Table 3.3 demonstrated that the adsorption capacity for aflatoxin B_1 increased as the temperature decreased. The high correlation coefficients of all adsorbents indicated that the linearized Freundlich model fitted the adsorption data better than the linearized Langmuir model. No adsorption data were applicable to the linearized Langmuir model. This implied that adsorption behavior of aflatoxin B_1 on these adsorbents were multilayer/multiple site adsorption on heterogeneous surfaces.

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Table 3.3 The linearized Langmuir and Freundlich fitting characteristics of isotherm data obtained from adsorption of aflatoxin B_1 onto six adsorbents at different temperatures

Adsorbents	Temperatures (^oC)	LM	FM		
		r^2	r^2	n^f	K_f
Commercial toxin binder	25	0.4626	0.8961	3.39	1.82×10^{16}
	37	0.4527	0.9633	3.18	1.01×10^{15}
	45	0.4755	0.9728	3.07	2.77×10^{14}
Commercial bentonite	25	0.7405	0.9731	2.12	1.35×10^{9}
	37	0.1783	0.9574	2.07	9.35×10^{8}
	45	0.2306	0.9444	1.90	4.72×10^{7}
Activated carbon	25	0.5739	0.9799	1.63	9.27×10^{7}
	37	0.0106	0.9905	1.04	1.33×10^{4}
	45	0.4714	0.9791	0.77	3.48×10^{2}
Commercial zeolite	25	0.4151	0.9541	1.30	1.50×10^{4}
	37	0.1380	0.9183	1.27	5.87×10^{3}
	45	0.0052	0.9503	1.23	2.95×10^{3}
Synthetic Na-X zeolite	25	0.3465	0.9884	1.24	9.30×10^{3}
	37	0.5630	0.9962	1.21	7.20×10^{3}
	45	0.5189	0.9942	1.21	6.71×10^{3}
Synthetic sodalite zeolite	25	0.1611	0.9914	1.23	8.55×10^{3}
	37	0.3566	0.9669	1.20	6.33×10^{3}
	45	0.2555	0.9944	1.15	3.39×10^{3}

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The adsorption ability of each adsorbent for aflatoxin B_1 was different by considering the adsorption capacity and affinity constants. The commercial toxin binder showed great adsorption ability for aflatoxin B_1, which had the highest adsorption capacity and affinity constants. The commercial toxin binder was a clay-based material consisting mainly of montmorillonite. Thus it demonstrated the highest cation exchange capacity (CEC) and conductivity. In general, montmorillonite clays are a very soft phyllosilicate mineral that typically forms in microscopic crystals [60]. They can swell considerably more than other clays with an addition of water. It has the properties of adsorbing organic substances either on its external surfaces or within it interlaminar spaces by the interaction with or substitution for the exchange cations presented in these spaces [3, 62]. Therefore, the commercial toxin binder was highly effective for adsorption of aflatoxin B_1 from aqueous solution. It is commonly used as an anticaking agent in animal feeds throughout the world [11, 61]. Whereas the commercial bentonite demonstrated good adsorption capability for aflatoxin B_1 *in vitro*, since the commercial bentonite is clay material, hydrated aluminosilicate clay primary composed of montmorillonite as a major constituent. Therefore, bentonite has received considerable recognition as adsorbents similar to the commercial toxin binder.

For activated carbon and the commercial zeolite, they could adsorb aflatoxin B_1 from aqueous solution. Activated carbon was able to adsorb aflatoxin B_1 because of the activated carbon surface is non-polar or only slightly polar, resulting in high affinity for non-polar adsorbates such as organics [34]. Besides, it has the large surface area and adsorbs compounds primarily by hydrogen bonding [6, 36]. In aqueous solution, it can adsorb most of mycotoxins efficiently. Activated carbon is a

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relatively unspecific adsorbent that adsorbs not only the mycotoxins but also essential nutrients. However, it was shown that high doses of activated carbon are beneficial in an acute poisoning situation concerning the intake of high amounts of aflatoxins, which trial with goats [6]. On the other hand, synthetic Na-X zeolite and synthetic sodalite zeolite were able to bind aflatoxin B_1, but less than the other adsorbents as evidenced by a significantly lower adsorption capacity and affinity constants. The synthetic Na-X zeolite and synthetic sodalite zeolite showed low ability to adsorb aflatoxin B_1. Probably, aflatoxin B_1 is too large molecule to enter the zeolite channels, and in fact, in synthetic zeolites, as opposed to naturals ones, the pore size distribution vary little and are generally concentrated within a narrow diameter range [19]. Therefore, the adsorption may be limited only to the external surface of the zeolite particle [63]. However, adsorption behavior differs considerably mainly on the chemical structure of both the adsorbent and the toxins [6, 13, 63]. Among the studied adsorbents, the commercial toxin binder was the most favor adsorbent, followed by the commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite, respectively.

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3.4 Isotherm fitting by 2D Table Curve program

In addition, experimental data were transferred to 2D Table Curve program. The isotherm equations in Table 3.4 to 3.5 were entered as user-defined functions. Each function has limits and beginning values or first approximations for the variable parameters. The values of the estimated maximum capacity (Q_{max}) and the distribution coefficient (K_d) were obtained from the double-logarithmic plot of the isotherm. The plot will normally present a break in the curve. The value on x-axis is an estimate of

K_d^{-1} and Q_{max} is estimate from the y-axis where the curve breaks. These values were entered into the user-defined functions.

Table 3.4 Isotherm equations used to fit the experimental data of aflatoxin B_1 adsorption onto different adsorbents by 2D Table Curve program [14]

Model	Fitting Equation
Generalized Langmuir Model (GLM)	$q = Q_{\max}\left[\dfrac{K_d C_e}{1+(K_d C_e)}\right]$
Generalized Freundlich Model (GFM)	$q = Q_{\max}\left[\dfrac{K_d C_e}{1+(K_d C_e)}\right]^n$
Modified Freundlich Model (MFM)	$q = Q_{\max}(K_d C_e)^n$

q is the adsorbed amount (mol/kg), C_e is the equilibrium concentration (mol/L), Q_{max} is the estimated maximum capacity (mol/kg), K_d is the distribution coefficient, n is the heterogeneity factor of adsorbent.

Table 3.5 User-defined function used to fit in 2D Table Curve program

Model	Fitting Equation
Generalized Langmuir Model (GLM)	Y=(A0*A1*X)/(1+A1*X)
Generalized Freundlich Model (GFM)	Y=A0*((A1*X)/(1+(A1*X)))^A2
Modified Freundlich Model (MFM)	Y=A0*(A1*X)^A2

Y is q, X is C_e, A0 is Q_{max}, A1 is K_d, A2 is n, respectively.

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The best-fit isotherms for aflatoxin B_1 adsorption onto six adsorbents at 25 ^{o}C were presented in Figure 3.6. Fitting characteristics obtained from the best-fit isotherm models were shown in Table 3.6.

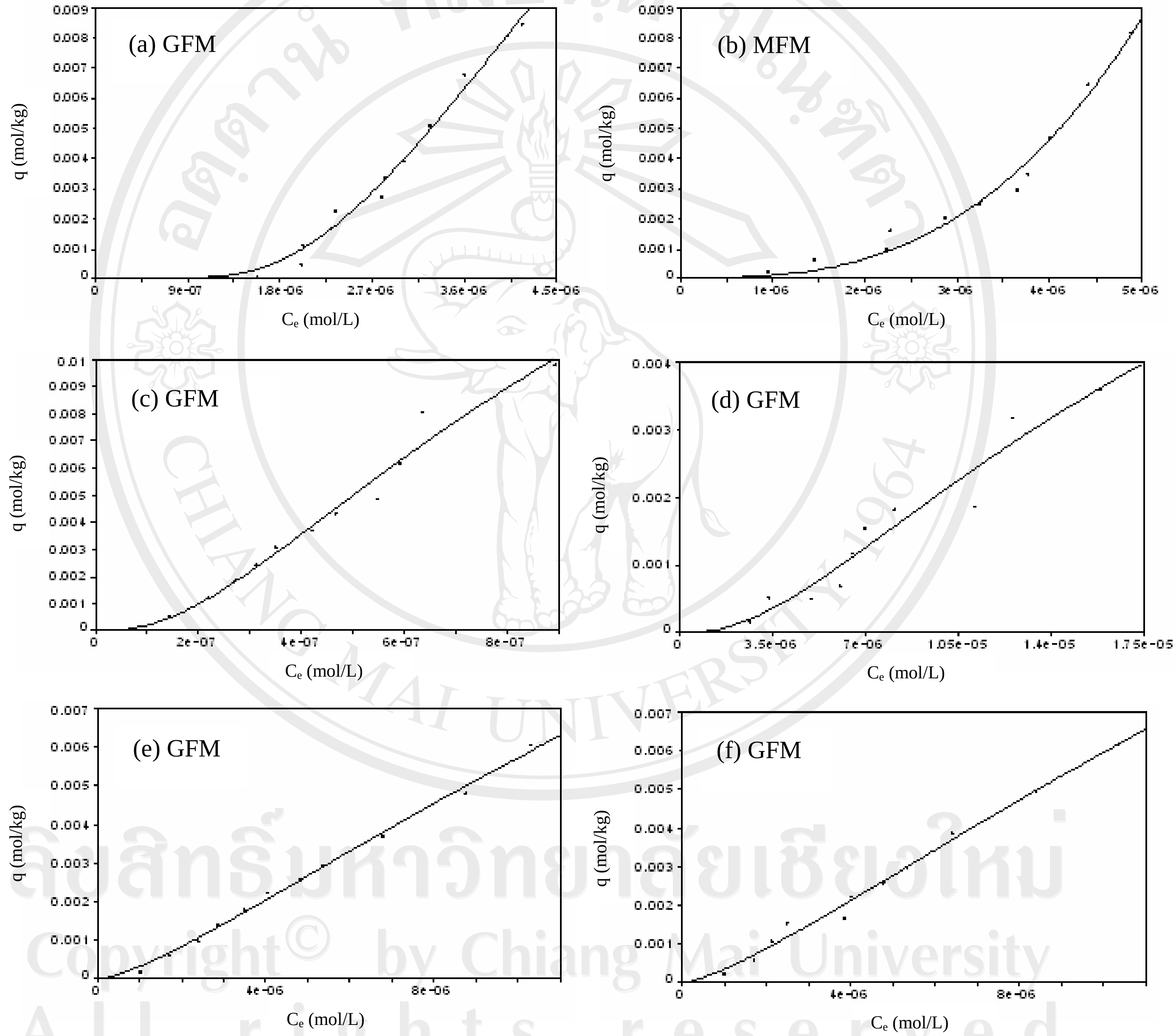

Figure 3.6 The best-fit isotherm for the adsorption of aflatoxin B_1 onto: (a) the commercial toxin binder, (b) the commercial bentonite, (c) activated carbon, (d) the commercial zeolite, (e) synthetic Na-X zeolite and (f) synthetic sodalite zeolite

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Table 3.6 Fitting characteristics for the best-fit isotherms

Adsorbent	r^2 of fitting model			Fitting characteristics [a]		
	GLM	GFM	MFM	Q_{max}	K_d	n
Commercial toxin binder	0.5886	0.9848[b]	0.9665	6.75×10^{-2}	1.43×10^{11}	1.21×10^{6}
Commercial bentonite	0.6921	0.9769	0.9790[b]	4.52×10^{-3}	2.52×10^{5}	2.82
Activated carbon	0.9030	0.9724[b]	0.9607	3.32×10^{-2}	2.46×10^{6}	3.19
Commercial zeolite	0.8732	0.9331[b]	0.9267	1.25×10^{-2}	1.16×10^{5}	2.87
Synthetic Na-X zeolite	0.9812	0.9957[b]	0.9945	3.12×10^{-2}	4.50×10^{4}	1.45
Synthetic sodalite zeolite	0.9759	0.9900[b]	0.9887	3.56×10^{-2}	3.92×10^{4}	1.41

[a] Fitting characteristics from the best fit isotherm, [b] The best fit isotherm for each adsorbent, GLM is the generalized Langmuir model, GFM is the generalized Freundlich model, MFM is the modified Freundlich model.

In Table 3.6 presented the values of the estimated maximum capacity, the distribution coefficient and the heterogeneity factor, obtaining from the best-fit isotherm models. From the results, it revealed that the generalized Freundlich model showed excellent fitting results for most adsorbents, as demonstrated by the higher correlation coefficient when compared to generalized Langmuir model at 25 ^{o}C. The generalized Freundlich model is a basic equation mostly used to explain multilayer adsorption with interaction between adsorbed molecules at low concentration, whereas the modified Freundlich model is a reduced form reasonably used when the equilibrium concentration is very low. These models were sufficiently flexible to give a good representation of data, and could reduce the error of the estimated parameters.

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Consequently, these models could be applied to the experimental data better than the linearized models.

From the best-fit isotherms, it was demonstrated that the estimated maximum capacities for the commercial toxin binder, the commercial bentonites, activated carbon, the commercial zeolite, synthetic Na-X zeolite and synthetic sodalite zeolite were 6.75×10^{-2}, 4.52×10^{-3}, 3.32×10^{-2}, 1.25×10^{-2}, 3.12×10^{-2}, and 3.56×10^{-2} mol/kg, respectively, whereas the distribution coefficients of them were 1.43×10^{11}, 2.52×10^{5}, 2.46×10^{6}, 1.16×10^{5}, 4.50×10^{4}, and 3.92×10^{4}, respectively. The heterogeneity factor for the commercial toxin binder, the commercial bentonites, activated carbon, the commercial zeolite, synthetic Na-X zeolite and synthetic sodalite zeolite were 1.21×10^{6}, 2.82, 3.19, 2.87, 1.45, and 1.41, respectively. Among the studied adsorbents, the commercial toxin binder was the best adsorbent for the adsorption of aflatoxin B_1 from aqueous solution as demonstrated with the higher estimated maximum capacity, the distribution coefficient and the heterogeneity factor than other commercial adsorbents. For both synthetic Na-X zeolite and synthetic sodalite zeolite, they demonstrated low capability to adsorb aflatoxin B_1 when compared with other adsorbents studied. They had the heterogeneity factor approached to 1.0, suggesting that the adsorption behavior of aflatoxin B_1 on these adsorbents followed monolayer mechanism.

The *in vitro* method may be useful for accurately predicting the efficacy of adsorbents *in vivo*. Consequently, all adsorbents must be test *in vivo* to prove their efficacy, safety, and lack of nutrient interactions before used in animal feeds [8, 23, 35-36].

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3.5 Characterizations of the adsorbents

3.5.1 Determination of particle size

The particle sizes of the commercial toxin binder, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite were determined using particle size analyzer. All experiments were done in triplicate. The average particle size of each adsorbent was revealed in Table 3.7.

Table 3.7 The particle size of different adsorbents

Adsorbent	Mean particle size (μm)			
	1	**2**	**3**	**average**
Commercial toxin binder	28.88	30.59	31.27	30.25
Commercial bentonite	18.51	18.86	18.61	18.66
Commercial zeolite	10.15	10.14	10.11	10.13
Synthetic Na-X zeolite	19.44	19.25	19.19	19.29
Synthetic sodalite zeolite	41.41	40.01	40.01	40.48

Particle size distribution is important for adsorption study. It can effect on adsorption rate that smaller particles provide quicker rates of adsorption [64]. From results in table above, the average particle size of the commercial toxin binder, the commercial bentonite, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite were 30.25, 18.66, 10.13, 19.29, and 40.48 μm, respectively.

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3.5.2 Determination of total surface area and pore size distribution

The commercial toxin binder, the commercial bentonite, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite were analyzed for the total surface area and pore size distribution by using surface area analyzer. The values of total surface area and pore size distribution were presented in Table 3.8.

Table 3.8 The total surface area and pore size distribution of different adsorbents

Adsorbent	Surface area (m^2/g)	Pore volume distribution (ml/g)	Average pore radius (Å)
Commercial toxin binder	77.75	0.1800	46.31
Commercial zeolite	9.19	0.0269	46.89
Synthetic Na-X zeolite	554.78	0.4041	14.57
Synthetic sodalite zeolite	184.96	0.1902	20.07

Pore size distribution is very useful of considerate the performance characteristics of the material, and is necessary to facilitate the adsorption process by providing adsorption sites and the appropriate channels to transport the adsorbate. The results in Table 3.8 presented the average pore radiuses for the commercial toxin binder, the commercial zeolite, synthetic Na-X zeolite and synthetic sodalite zeolite were 46.31, 46.89, 14.57, and 20.07 Å, respectively, whereas their surface area were 77.75, 9.19, 554.78, and 184.96 m^2/g, respectively. For determined pore radii, it can be classified that pore with opening exceeding 500 Å in radius is called “macropores”. The term “micropores” describes pores with radii not exceeding 20 Å. Pore size of

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intermediate is called “mesopores” [41]. Synthetic Na-X zeolite had small pore radius (<20 Å; micropores) thus aflatoxin B_1 might not enter to the channel of synthetic Na-X, thus the adsorption may be limited only to the external surface of synthetic Na-X zeolite particle [63]. Even though synthetic Na-X zeolite has higher surface area than another adsorbents, but it adsorbed aflatoxin B_1 the least, as established by the lowest adsorption capacity. Probably, the synthetic Na-X zeolite was washed not clean enough so that residues were remaining on the surface, which made its surface not active for aflatoxin B_1. Some ions on surface could diminish the adsorption of aflatoxin B_1. In addition, adsorption capability significantly involves the type and density of active sites on the adsorbent. It could be explained for synthetic sodalite zeolite as the same as synthetic Na-X zeolite. For the commercial zeolite, it had small particle size, but small surface area due to slightly low pore volume distribution. However, it showed more slightly adsorbed aflatoxin B_1 than synthetic Na-X zeolite and synthetic sodalite zeolite. This possibly due to the commercial zeolite had larger average pore radius than synthetic Na-X zeolite and synthetic sodalite zeolite. The adsorption of aflatoxin B_1 might be occurred in the internal surface or/and external surface. The uptake might expect to be irrelevant to the particle size.

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3.5.3 Determination of total carbon content

Six different adsorbents including the commercial toxin binder, the commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite were investigated for the total carbon content. This study was carried out with CHNS/O analyzer. All experiments were conducted in triplicate. The percentages of the total carbon content of different adsorbents were presented in Table 3.9.

Table 3.9 The total carbon contents of different adsorbents

Adsorbent	**Total carbon content (%)**			**Average (%)**
	1	**2**	**3**	
Commercial toxin binder	0.50	0.42	0.35	0.42
Commercial bentonite	0.16	0.80	0.89	0.84
Activated carbon	85.67	83.46	84.08	84.40
Commercial zeolite	0.35	0.31	0.30	0.32
Synthetic Na-X zeolite	1.22	1.16	1.40	1.26
Synthetic sodalite zeolite	0.95	0.95	0.91	0.94

The results in Table 3.9 presented average percentages of the total carbon contents of the commercial toxin binder, commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite were 0.42, 0.84, 84.40, 0.32, 1.26, and 0.94 %, respectively. From the results, it revealed that activated carbon had the highest total carbon content because activated carbon is formed by pyrolysis of organic materials [6, 31]. As the commercial toxin binder, commercial bentonite, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite had relatively low total carbon content, which suggested that total carbon content might not significantly affect the adsorption of aflatoxin B_1 adsorption on these adsorbents.

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3.5.4 Determination of pH, conductivity and cation exchange capacity (CEC)

For more information, the values of pH, conductivity and cation exchange capacity (CEC) of the commercial toxin binder, commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite were analyzed to help describe adsorptive behavior of aflatoxin B_1 on different adsorbents. The values of pH, conductivity and cation exchange capacity of six adsorbents were presented in Table 3.10.

Table 3.10 The values of pH, conductivity and cation exchange capacity (CEC) of different adsorbents

Adsorbent	pH	Conductivity (ms/cm)	Cation exchange capacity (meq/100g)
Commercial toxin binder	7.04	3.947	54.80
Commercial bentonite	8.10	1.790	78.50
Activated carbon	9.11	0.943	17.39
Commercial zeolite	9.75	0.998	191.30
Synthetic Na-X zeolite	10.24	1.125	139.13
Synthetic sodalite zeolite	10.71	1.347	121.74

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From Table 3.10, the pH values of the commercial toxin binder, commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite were 7.04, 8.10, 9.11, 9.75, 10.24, and 10.71, respectively, whereas their conductivities were 3.947, 1.790, 0.943, 0.998, 1.125, and 1.347 ms/cm, respectively. The cation exchange capacity for the commercial toxin binder, commercial bentonite, activated carbon, the commercial zeolite, synthetic Na-X zeolite, and synthetic sodalite zeolite were 54.80, 78.50, 17.39, 191.30, 139.13, and 121.74 meq/100g, respectively. The high pH values of all zeolites may due to when highly negative charge containing zeolite immersed in water, zeolite can attract hydrogen ion (H^+) from water molecule that make the hydroxyl ions (OH^-) in solution increased, which lead to high pH value when the exchanger is equilibrated [63]. For clay-based mineral, the pH value is related to cation exchange capacity because as pH value increase (become less acid), the amount of negative charges on the colloids increase, thereby increasing cation exchange capacity.

Structural characterization of adsorbents is useful for described efficiency for adsorption of aflatoxin B_1 from aqueous solution. The active site density is important for adsorption of aflatoxin B_1 on surface of adsorbent. However, the efficiency of adsorption is dependent on structural properties of both adsorbent and toxin [6, 13, 63].

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