Dozens of adsorption kinetic models

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The adsorption kinetics has been investigated for 120 years and the development of kinetic model has been proceeded in order to obtain the particular kinetic model which better agreed with the experimental data.

As a result, dozens of adsorption kinetic models were established. The adsorption kinetic models are shown in a table.

Table. Adsorption Kinetic Models

No	Name	Differential Form	Integrated or Linear Form
1	pseudo-first-order(PFO)	$\frac{dq}{dt} = k_1(q_e - q)$	$q = q_e[1 - \exp(-k_1 t)]$, $\ln(q_e - q) = \ln q_e - k_1 t$
2	pseudo-second-order(PSO)	$\frac{dq}{dt} = k_2(q_e - q)^2$	$q = \frac{k_2 q_e^2 t}{1 + k_2 q_e t}$, $\frac{t}{q} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t$

3	mixed-order(MOE)	$\frac{dF}{dt} = \frac{k_1}{1 - f_2}(1 - F)(1 - f_2F)$	$q = q_e\left(\frac{1 - \exp(-k_1t)}{1 - f_2\ \exp(-k_1t)}\right)$
4	pseudo-n-order (PnO)	$\frac{dq}{dt} = k_n(q_e - q\ )^n$	$q = q_e - [(n-1)k_nt + q_e^{1-n}]^{1/1-n}, n \neq 1$
5	modified PFO (MPFO-1)	$\frac{dq}{dt} = k_1(q_e / q)(q_e - q)$	$q_e / q + \ln(q_e - q) = \ln q_e - k_1t$
6	modified PFO (MPFO-2)	$\frac{dq}{dt} = k_1(q_e^2 / q^2)(q_e - q)$	$\ln(1 - q_e / q) + (q^2 / 2q_e^2) + q_e / q = -k_1t$
7	modified PSO(MPSO-1)	$\frac{dq}{dt} = k_2(q_e / q)(q_e - q)^2$	$\ln(1 - q_e / q) + q / (q_e - q) = k_2tq_e$
8	modified PSO(MPSO-2)	$\frac{dq}{dt} = k_2(q_e^2 / q^2)(q_e - q)^2$	$2\ln(1 - q_e / q) + q / (q_e - q) + + q_e / q - 1 = k_2tq_e$
9	modified PnO (MPnO)	$\frac{dq}{dt} = k_n(q_e^{n-1} / q^{n-1})(q_e^n - q^n)$	$q = q_e[1 - \exp(-nk_n't)]^{1/n}$
10	Elovich's	$\frac{dq}{dt} = a\exp(-\alpha q)$	$q = \alpha\ln(a\alpha) + \alpha\ln(t)\ , a\alpha t >> 1$
11	Ritchie's	$\frac{d\theta}{dt} = \alpha(1 - \theta)^n$	$\frac{1}{(1 - \theta)^{n-1}} = (n-1)\alpha t + 1, n \neq 1$ $\theta = 1 - \exp(-\alpha t)\ ,\ n = 1$

12	intra-particle diffusion model (IDM)	-	$q = k_D\sqrt{t} + C$
13	multi-exponential equation (m-Exp)	$\frac{dF}{dt} = \sum_{i=1}^{n} f_i k_i \exp(-k_i t)$	
14	mixed surface reaction + diffusion controlled model (MSD)	$\frac{dF}{dt} = kC_0\left(1 + \frac{\tau^{1/2}}{t^{1/2}}\right) \times (1 - u_{eq}F)(1 - F)$	$q = q_e \frac{\exp(at + bt^{1/2}) - 1}{u_{eq}\exp(at + bt^{1/2}) - 1}$
15	exponential kinetic model (Exp)	$\frac{dF}{dt} = k'[\exp(1 - F) - 1]$	$F = \frac{q}{q_e} = \ln[2.72 - 1.72\exp(-k't)]$
16	hyperbolic tangent model (HTM)	$\frac{dq}{dt} = q_e k(1 - \tanh^2 kt)$	$\ln\frac{q_e + q}{q_e - q} = 2kt$
17	Fractal model	$\frac{dC}{dt^{\alpha}} = k^n C^n$	$C = C_0[1 + (n-1)(t/\tau)^{\alpha}]^{-1/(n-1)}$, $\tau = [C_0^{n-1}k]^{-1/\alpha}$
18	Fractal-like PFO(FPFO)	$\frac{dq}{dt^{\alpha}} = k_1'(q_e - q)$	$q = q_e[1 - \exp(-k_1' t^{\alpha})]$
19	Fractal-like PSO(FPSO)	$\frac{dq}{dt^{\alpha}} = k_2'(q_e - q)^2$	$q = \frac{k_2' q_e^2 t^{\alpha}}{1 + k_2' q_e t^{\alpha}}$

20	Fractal-like MOE(FMOE)	$\frac{dF}{dt^{\alpha}} = \frac{k_1'}{1-f_2}(1-F)(1-f_2F)$	$q = q_e\left(\frac{1-\exp(-k_1't^{\alpha})}{1-f_2\exp(-k_1't^{\alpha})}\right)$
21	fractal-like Exp (FExp)	$\frac{dF}{dt^{\alpha}} = k''[\exp(1-F)-1]$	$F = \frac{q}{q_e} = \ln[2.72-1.72\exp(-k''t^{\alpha})]$
22	Langmuir–Freundlich model	$\frac{d\theta}{dt} = k_a'C(1-\theta)^n - k_d\theta^n$	-
23	Multisite Langmuir model	$\frac{d(q_i/q_{si})}{dt} = k_{ai}C_i\left(1-\sum_{j=1}^{n} q_i/q_{si}\right)^{a_i} - k_{di}q_i/q_{si}$	-
24	Extensions of the general multicomponent rate model	$\frac{\partial C_{si}}{\partial t} = k_{ai}C_i\left(C_i^{\infty} - \sum_{j=1}^{n}\theta_{ij}C_{sj}\right) - k_{di}C_{si}$	-
25	Binary-solute Langmuir-type adsorption kinetic model	$\begin{cases}\frac{dC_{s1}}{dt} = k_{a1}C_1(C_{11}-C_{s1}-\theta C_{s2}) - k_{d1}C_{s1}\\ \frac{dC_{s2}}{dt} = k_{a2}C_2(C_{12}-C_{s1}-C_{s2}) - k_{d2}C_{s2}\end{cases}$	-

26	Appropriate form of the multisite Langmuir model	$\begin{cases} k_{AA} = (k_{bo})_A[1 + (a_A - 1)\theta_A - \theta_B] \\ k_{AB} = (k_{bo})_A a_A \theta_A \\ k_{BA} = (k_{bo})_B a_B \theta_B \\ k_{BB} = (k_{bo})_B[1 - \theta_A + (a_A - 1)\theta_B] \end{cases}$	-
27	Unified kinetic model for adsorption and desorption	$\frac{d\theta_i}{dt} = k_{ai} / k_{di} C_A^{j_i}(1 - \theta_i)\theta_{i-1} - \theta_i^{j_i}(1 - \theta_{i+1})$	-