**Adsorption Kinetic Models**

**1. Pseudo-First-Order Model**

**Formula:**

* qt​: amount adsorbed at time t (mg/g)
* qe​: adsorption capacity at equilibrium (mg/g)
* k1​: rate constant of pseudo-first-order adsorption (min-1)

**Description:**  
Assumes the adsorption rate is proportional to the number of unoccupied sites. Often describes physisorption processes, typically valid in early stages of adsorption.

**2. Pseudo-Second-Order Model**

**Formula:**

* qt , qe​ as above
* k2​: rate constant of pseudo-second-order adsorption (g·mg-1·min-1)

**Description:**  
Assumes chemisorption is the rate-limiting step involving valency forces through sharing or exchange of electrons. Commonly fits entire adsorption process well.

**3. Intraparticle Diffusion Model (Weber-Morris Model)**

**Formula:**

* qt​: adsorbed amount at time t (mg/g)
* kid​: intraparticle diffusion rate constant (mg/g·min0.5)
* CCC: intercept related to boundary layer thickness

**Description:**  
Checks if intraparticle diffusion controls adsorption rate. If plot of qt vs t0.5 is linear and passes through origin (C ≈ 0), intraparticle diffusion is the sole rate-limiting step.

**4. Elovich Model**

**Formula:**

* qt adsorbed amount at time t (mg/g)
* α: initial adsorption rate (mg/g·min)
* β: desorption constant related to surface coverage (g/mg)

**Description:**  
Describes adsorption on heterogeneous surfaces, where adsorption rate decreases exponentially due to surface coverage or activation energy barriers.

**5. Avrami Model**

**Formula:**

* qt ​: adsorbed amount at time t (mg/g)
* qe ​: adsorption capacity at equilibrium (mg/g)
* k: Avrami rate constant (min-n)
* n: Avrami exponent, relates to mechanism complexity

**Description:**  
Originally for crystallization kinetics, applied in adsorption to model multi-mechanism processes and complex adsorption behavior.

**Bonus: Boyd Model**

**Formula:**

* B(t): Boyd function
* F(t): fractional adsorption at time t

**Description:**  
Used to determine whether film diffusion or particle diffusion controls the adsorption rate by analyzing the linearity and intercept of B(t) vs time plots.

**Bangham Model**

**Equation:**

**Where:**

* C0​: Initial dye concentration in the solution (mg/L)
* qt​: Amount of dye adsorbed at time t (mg/g)
* m: Mass of adsorbent (g)
* V: Volume of dye solution (L)
* k: Bangham rate constant
* α: Bangham diffusion parameter
* t: Contact time (min)

**Description:**  
The Bangham model is commonly used to investigate whether pore diffusion plays a significant role in the adsorption process. It is particularly applicable when adsorption occurs in porous adsorbents, and the rate of diffusion within these pores affects the overall rate of dye uptake. The model assumes that the adsorbate must diffuse through a network of micropores before being adsorbed on the inner surfaces.

A **linear relationship** between and log(t) suggests that the adsorption process is **diffusion-controlled within the pores** of the adsorbent.

* The **slope α** provides insight into the **extent of pore diffusion control**.
* The **intercept log(k)** represents the system's adsorption capacity and energy.

**1. Understanding the Mechanism**

Each model is based on **different assumptions**:

* **Pseudo-first-order**: assumes physisorption (weak interactions)
* **Pseudo-second-order**: assumes chemisorption (stronger binding)
* **Boyd**: tells you whether external or intraparticle diffusion is rate-limiting
* **Bangham**: checks if pore diffusion matters
* **Weber-Morris**: sees how well diffusion within particles explains the data
* **Elovich**: for systems with heterogeneous surfaces (common in biochar, GAC)
* **Avrami**: complex kinetics, often tied to nucleation or fractal-type behavior

🧠 **Purpose**: Comparing them reveals **which mechanism dominates** under certain conditions (e.g., different biochars, Fe loadings, H₂O₂ doses, etc.).

Her model farklı bir süreci temsil eder:

* **Pseudo-first-order** → fiziksel adsorpsiyon
* **Pseudo-second-order** → kimyasal adsorpsiyon
* **Boyd, Weber-Morris, Bangham** → difüzyon mekanizmaları (film, partikül içi, gözenek vs.)
* **Elovich** → yüzey heterojenliği
* **Avrami** → kompleks, çok adımlı kinetik davranışlar

🧠 **Yani bu modelleri kıyaslamak**, sistemde **hangi mekanizma baskın** onu anlamamızı sağlar.