



Eco-Friendly Competitive Adsorption of Binary Dyes Using Moroccan Cactus Peel: A Green Approach to Wastewater Treatment

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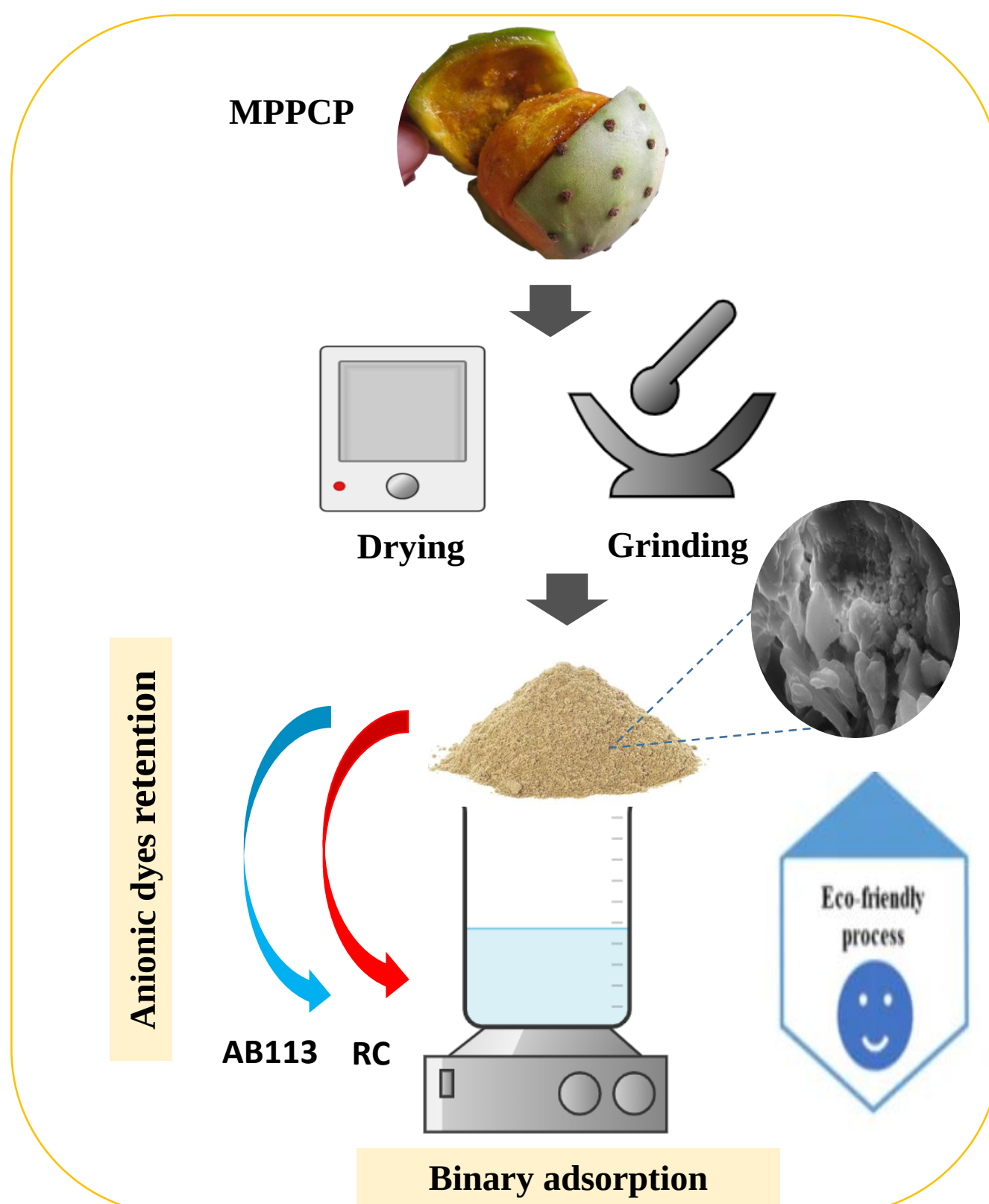


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Introduction

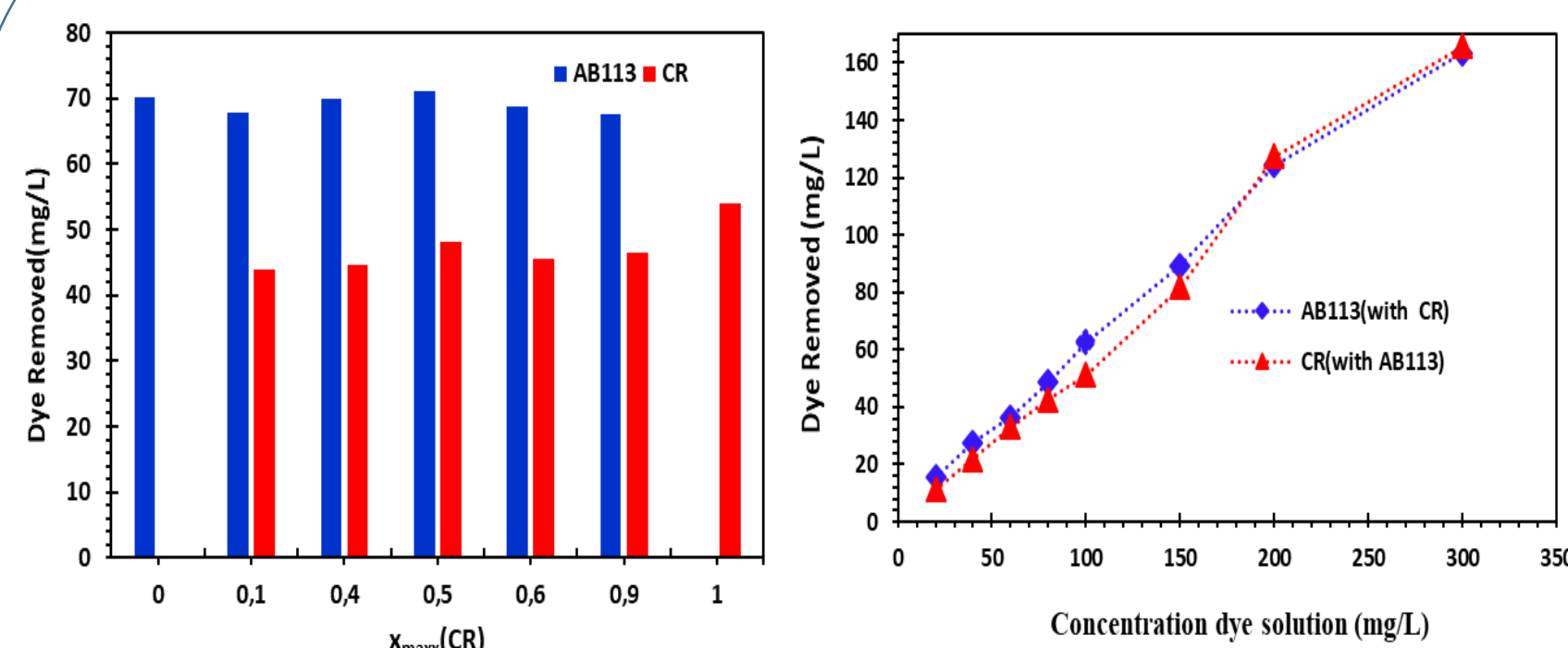
The discharge of synthetic dyes by textile industries poses a major threat to aquatic ecosystems due to their toxicity, chemical stability, and resistance to biodegradation. In this context, our study proposes an eco-friendly alternative by using Moroccan *Prickly Pear Cactus Peel* (MPPCP), untreated agricultural waste, as a natural adsorbent. Through kinetic, isotherm, and thermodynamic investigations, we assess its adsorption performance for the competitive removal of Acid Blue 113 and Congo Red dyes. This work supports key principles of green chemistry by promoting waste valorization, renewable resources, and sustainable water treatment technologies.

Methods

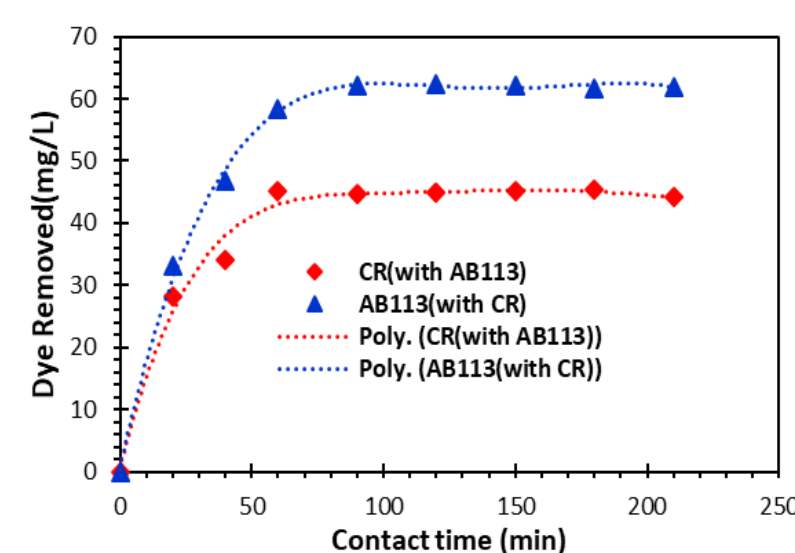


Results

Factors affecting adsorption

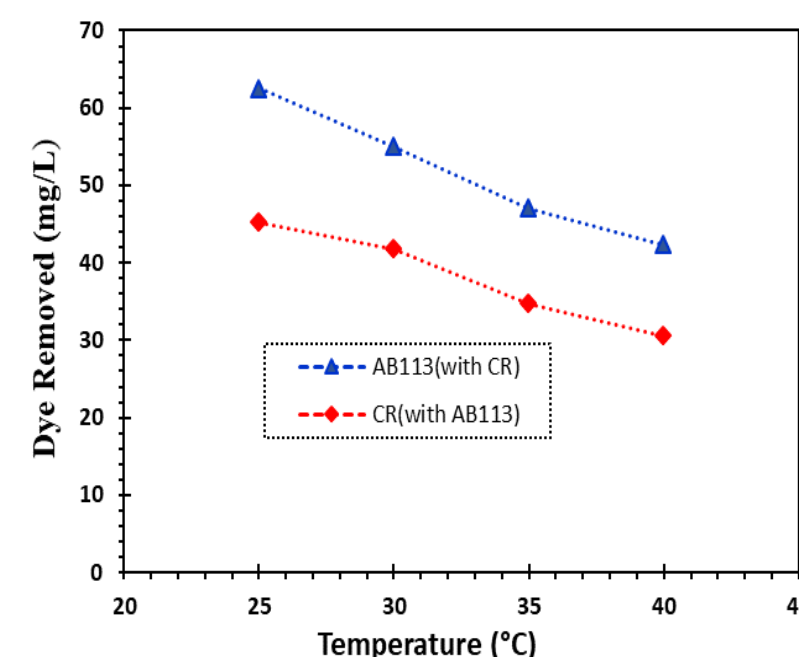


- In single systems, AB113 was more efficiently adsorbed (14.05 mg/g) than CR (10.79 mg/g).
- The overall decrease in adsorption compared to single systems confirms a competitive effect for active sites between the two dyes.
- At equal mass fraction (0.5:0.5), MPPCP achieved high adsorption for both dyes: → AB113: 14.23 mg/g, CR: 9.65 mg/g.



- Short equilibrium time means lower energy requirements.
- Fast initial uptake demonstrates efficient pollutant removal, reducing reactor volume and processing time

- Adsorption capacity increased sharply for both dyes as initial concentration increased.
- The increase in dye removal is attributed to a greater driving force for mass transfer between the solution and MPPCP surface



- Adsorption capacity decreased with increasing temperature, indicating exothermic behavior
- The decrease suggests reduced dye-adsorbent interaction at higher temperatures, possibly due to: Increased dye solubility in water or reduced surface binding or active site deactivation.

Adsorption in binary system

System	Pseudo-first-order			Pseudo-second-order			q _{exp} (mg/g)
	q _e (mg/g)	K ₁ (min ⁻¹)	R ²	q _e (mg/g)	K ₂ (g.mg ⁻¹ min ⁻¹)	R ²	
AB113 (with CR)	60.70	0.085	0.926	13.45	0.0035	0.995	12.45
CR (with AB113)	21.24	0.072	0.961	9.63	0.0097	0.996	9.00

- Pseudo-second order (PSO) model best describes the adsorption of AB113 and CR onto MPPCP, and q_{e,calc} ≈ q_{e,exp}, indicating chemisorption may be the rate-limiting step.

System	Langmuir parameters			Freundlich parameters		
	q _L (mg/g)	K _L (L/mg)	R ²	1/n	K _f (mg/g)	R ²
AB113 alone	34.13	10 ⁻²	0.967	0.778	0.543	0.977
CR alone	43.89	7.5*10 ⁻³	0.979	0.939	0.500	0.971
AB113 (with CR)	22.42	3.2*10 ⁻²	0.946	0.735	0.869	0.977
CR (with AB113)	40.48	8.12*10 ⁻³	0.970	0.960	0.297	0.982

- Both isotherm models confirm MPPCP's strong affinity for anionic dyes.
- In the binary system, the Freundlich model provided a better fit, as evidenced by higher R² values. This suggests heterogeneous adsorption sites and multilayer adsorption behavior when both dyes are present.

System	q _{L, single} (mg/g)	q _{L, mix} (mg/g)	q _{L, mix} / q _{L, single}
AB113 alone	34.13	-	< 1
AB113 (with CR)	-	22.42	
CR alone	43.89	-	< 1
CR (with AB113)	-	40.48	

- The ratio evaluates the effect of one dye on the adsorption of the other.
- The results indicates antagonistic interaction between dyes.
- The presence of a second dye reduces the adsorption capacity of the first due to competition for active sites

Potential of this Study

- Utilization of agricultural waste (prickly pear peel) as an unmodified, low-cost adsorbent, valorizes local biomass and minimizes environmental impact.
- Fast kinetics and good uptake capacity allow efficient treatment with minimal contact time, lowering process cost.
- Supports key green chemistry principles:
 - ✓ Use of renewable feedstocks
 - ✓ Safer processes and waste prevention