Journal of Colloid and Interface Science 515 (2018) 172–188

Contents lists available at ScienceDirect

Journal of Colloid and Interface Science

journal homepage: www.elsevier.com/locate/jcis

Regular Article

Trimellitated sugarcane bagasse: A versatile adsorbent for removal of cationic dyes from aqueous solution. Part I: Batch adsorption in a monocomponent system

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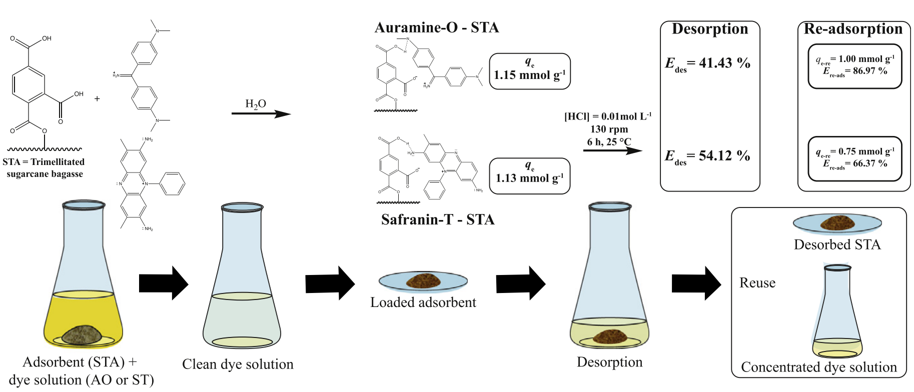
GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 19 November 2017
Revised 4 January 2018
Accepted 5 January 2018
Available online 6 January 2018

Keywords:
Sugarcane bagasse
Adsorption
Auramine-O

ABSTRACT

Trimellitated-sugarcane bagasse (STA) was used as an environmentally friendly adsorbent for removal of the basic dyes auramine-O (AO) and safranin-T (ST) from aqueous solutions at pH 4.5 and 7.0. Dye adsorption was evaluated as a function of STA dosage, agitation speed, solution pH, contact time, and initial dye concentration. Pseudo-first- and pseudo-second-order, Elovich, intraparticle diffusion, and Boyd models were used to model adsorption kinetics. Langmuir, Dubinin-Radushkevich, Redlich-Peterson, Sips, Hill-de Boer, and Fowler-Guggenheim models were used to model adsorption isotherms, while a Scatchard plot was used to evaluate the existence of different adsorption sites. Maximum adsorption capacities for removal of AO and ST were 1.005 and 0.638 mmol g^{-1} at pH 4.5, and 1.734 and 1.230 mmol g^{-1} at pH 7.0, respectively. Adsorption enthalpy changes obtained by isothermal titration

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https://doi.org/10.1016/j.jcis.2018.01.025
0021-9797/

Nomenclature

AO	auramine-O
a_R	Redlich-Peterson constant (L mmol^{-1})
α	initial adsorption rate (mmol g^{-1} min^{-1})
b	Langmuir binding constant (L mmol^{-1})
B	solid characteristic energy towards a reference adsorbate (mol^2 kJ^{-2})
BET	Brunauer, Emmett, and Teller
BJH	Barret, Jayner, and Halenda
β_{des}	desorption constant (g mmol^{-1})
β	Redlich-Peterson exponent (dimensionless)
C	concentration at time t or equilibrium (mmol L^{-1})
c	interaction energy among adsorbed molecules (kJ mol^{-1})
CN	coordination number
D_i	effective diffusion coefficient (m^2 min^{-1})
DMA	*N*,*N*-dimethylacetamide
DTGS	deuterated triglycine sulfate detector
D-R	Dubinin-Radushkevich
$\Delta_{ads}H$	adsorption enthalpy change (kJ mol^{-1})
$\Delta_{ads}H^{dye\text{-}dye}$	enthalpy changes associated with the dye-dye interactions on the adsorbent surface (kJ mol^{-1})
$\Delta_{ads}H^{dye\text{-}STA}$	enthalpy changes associated with the formation of dye-adsorbent interactions (kJ mol^{-1})
$\Delta_{ads}H^{desol}$	enthalpy changes associated with the desolvation of adsorption sites on the STA surface and dye molecules in the bulk solution (kJ mol^{-1})
E	characteristic energy of adsorption (kJ mol^{-1})
EDX	energy dispersive X-ray spectroscopy
E_{des}	desorption efficiency (%)
$E_{re\text{-}ads}$	re-adsorption efficiency (%)
ε	adsorption potential (kJ mol^{-1})
f	fractional loading
F-G	Fowler-Guggenheim
FTIR	Fourier transform infrared spectroscopy
γ_e	dye activity coefficient at equilibrium
h	initial adsorption rate of the pseudo-second-order kinetic model (mmol g^{-1} min^{-1})
H-B	Hill-de Boer
IARC	international Agency for Research on Cancer
ITC	isothermal titration calorimetry
IR	infrared
k_1	pseudo-first-order rate constant (min^{-1})
k_2	pseudo-second-order rate constant (g mmol^{-1} min^{-1})
K_a	thermodynamic equilibrium constant (dimensionless)
K_{HB}	Hill-de Boer constant (L mmol^{-1})
k_i	intraparticle diffusion rate constant (mmol g^{-1} min$^{-1/2}$)
K_{FG}	Fowler-Guggenheim constant (L mmol^{-1})
K_R	Redlich-Peterson constant (L g^{-1})
μ	ionic strength (mol L^{-1})
n_{COOH}	number of carboxylic acid groups (mmol g^{-1})
n	Sips model parameter associated with the heterogeneity of the adsorption system
n_i	amount of dye (in mol)
N	number of experimental data points
υ	number of degrees of freedom
P	number of variables of the model
P	equilibrium pressure
P_0	saturation pressure
PFO	pseudo-first-order
pH_{PZC}	point of zero charge
PSO	pseudo-second-order
pwg	percent weight gain (%)
Py	pyridine
q	adsorption capacity (mmol g^{-1})
q_s	maximum adsorption capacity (mmol g^{-1})
$q_{i,int}$	heats in the reaction cell at the i^{th} injection in the presence of the STA adsorbent (kJ)
$q_{i,dil}$	heats in the reaction cell at the i^{th} injection in the absence of the STA adsorbent (kJ)
Q_{max}	maximum adsorption capacity (mmol g^{-1})
$Q_{max,e}$	maximum adsorption capacity at equilibrium (mmol g^{-1})
$Q_{re\text{-}ads}$	maximum re-adsorption capacity (mmol g^{-1})
R	dye removal percentage (%)
R-P	Redlich-Peterson
R^2	determination coefficient
RSS	residual sum of squares
SB	sugarcane bagasse
ST	safranin-T
STA	trimellitated sugarcane bagasse
STA-AO	STA-loaded with auramine-O
STA-ST	STA-loaded with safranin-T
STA-DAO	STA after desorption of auramine-O
STA-DST	STA after desorption of safranin-T
t_e	equilibrium time (min)
t_0	the time constant (min)
θ	fractional coverage
V	volume of the dye solution (L)
w_i	weighting coefficient
w_{STA}	weight of STA (g)
$w_{STA,dye}$	weight of the STA loaded with a dye (g)
w'_{STA}	weight of STA in $w_{STA,dye}$ (g)
w'_{dye}	weight of dye not desorbed from the STA adsorbent after the desorption (mg)
w''_{dye}	weight of dye adsorbed on the STA in the re-adsorption experiment (mg)
χ^2	chi-square
χ^2red	reduced chi-square
y_i	experimental data point
$\hat{y}_i$	estimated data point calculated by the model
z	charge of the adsorbate

Subscripts

ads	adsorption
re-ads	re-adsorption
e	equilibrium
exp	experimental
t	time
T	theoretical value obtained from the model

Safranin-T
Desorption
Isothermal titration calorimetry

calorimetry (ITC) ranged from −21.07 ± 0.25 to −7.19 ± 0.05 kJ mol^{-1}, indicating that both dyes interacted with STA by physisorption. Dye desorption efficiencies ranged from 41 to 51%, and re-adsorption efficiencies ranged from 66 to 87%, showing that STA can be reused in new adsorption cycles. ITC data combined with isotherm studies allowed clarification of adsorption interactions.