Supplementary Information

Harnessing Carbon-Based Material from Food Waste Digestate for Dye Adsorption: The Role of Hydrogel Beads in Enhancing Stability and Regenerative Capacity

Salaheddine FARSAD^{1*}, Asma AMJLEF¹, Ayoub CHAOUI¹, Aboubakr BEN HAMOU¹, Chaima HAMMA¹, Mohamed BENAFQIR¹, Amane JADA^{2,3}, Noureddine EL ALEM¹.

¹Laboratory of Materials and Environment, Ibn Zohr University, Agadir, 80000, Morocco ²Institute of Materials Science of Mulhouse (IS2M), Haute Alsace University, Mulhouse 68100, France ³Strasbourg University, Strasbourg 67081, France

*Corresponding author: <u>farsadsalaheddine@gmail.com</u>; <u>n.elalem@uiz.ac.ma</u>

1. Experimental set-up

Anaerobic batch tests were carried out with 500 ml glass reactors (300 ml active volume), Each reactor which was submerged in a water bath with magnetic stirrers for mixing with intermittent agitation. The process was evaluated in mesophilic temperature ($38 \pm 2 \, ^{\circ}$ C). Different conditions were evaluated: pH, Storage time, % of inoculum. The amount of methane produced is measured via the water displacement method. The tests were duplicated and only the average of methane production was reported. The characterization of food waste and inoculum are presented in **Table S1**.

Parameters	Unit	Food waste	Inoculum
pН	-	4,14	5,75
Conductivity	$\mu S / cm$	804	-
Total Solid (TS)	g/l	88.6	153.5
Mineral Solid (MS)	g/l	9.04	130.8
Volatil Solid (VS)	g/l	79.56	22.720
% VS from TS	%	89.8	14.80

Table S1. Mean values of physicochemical parameters of food waste and Inoculum.

Run	лIJ	Storage time	Inoculum percentage	Methane volume
	pm	(days)	(%)	(CH ₄)
1	7,5	2	50%	104
2	7,5	0	25%	184
3	7,5	2	25%	216
4	5,5	2	25%	71

 Table S2. Experiments results

Table S3. Equations used to fit the data of adsorption experiments of MB onto CM-HNO₃ and CM-HNO₃@Alginate beads.

Equation	Name	Parameters	References
$Q_{ads} = \frac{(C_0 - C_e) * V}{m}$ $%R = \frac{(C_0 - C_e) * 100}{C_0}$	Adsorption capacity Removal efficiency	C_0 and C_e (mg/L) are the initial and equilibrium dye concentrations, respectively, V (L) is the volume of solution, and m (g) is the mass of adsorbent.	[1]
$\frac{1}{Q_e} = \frac{1}{Q_{max}} + \frac{1}{Q_{max}K_L} * \frac{1}{C_e}$	Langmuir isotherm	Q_e (mg/g) is the amount adsorbed at equilibrium, Q_m (mg/g) is the maximum adsorption capacity for complete monolayer coverage, and K _L (L/mg) is the equilibrium adsorption constant.	[2]
$lnQ_e = lnK_f + \frac{1}{n}lnC_e$	Freundlich isotherm	$K_f((mg/g)(L/mg)^{1/n})$ and n are the Freundlich constants related to the adsorption capacity of adsorbent and heterogeneity of adsorption, respectively.	[3]
$R_L = \frac{1}{1 + K_L C_0}$	Equilibrium parameter	K_L (L/mg) is the Langmuir constant and C_0 (mg/L) is the initial concentration. RL indicates the type of isotherm: unfavorable (R _L >1), linear (R _L =1), favorable (0 <r<sub>L<1)</r<sub>	[4]

$ln(Q_e - Q_t) = lnQ_e - K_1 t$	Pseudo-first- order	Qe and Qt are the adsorbed amounts at equilibrium and at times t,	[5]
$\frac{t}{Q_t} = \left(\frac{1}{K_2 Q_e^2}\right) + \frac{t}{Q_e}$	Pseudo- second-order	respectively. K ₁ : the rate constant; K ₂ : rate constant.	[6]
$\Delta G = -RTlnK_d$	Gibbs free energy	ΔG° : Gibbs free energy change ; K_d : equilibrium constant ; R : gas	[8,9]
$LnK_d = -\frac{\Delta H^{\circ}}{RT} + \frac{\Delta S^{\circ}}{R}$	van't Hoff	constant ; I : temperature ; ΔS° : entropy change ; ΔH° : enthalpy change.	

References

- [1] M. Zbair, H. Ait Ahsaine, Z. Anfar, Porous carbon by microwave assisted pyrolysis: An effective and low-cost adsorbent for sulfamethoxazole adsorption and optimization using response surface methodology, J. Clean. Prod. (2018). https://doi.org/10.1016/j.jclepro.2018.08.155.
- I. Langmuir, THE CONSTITUTION AND FUNDAMENTAL PROPERTIES OF SOLIDS AND LIQUIDS. PART I. SOLIDS., J. Am. Chem. Soc. 38 (1916) 2221–2295. https://doi.org/10.1021/ja02268a002.
- [3] H.M.F. Freundlich, Over the adsorption in solution, J. Phys. Chem. 57 (1906) 1100–1107.
- [4] R.H.A.L.L. Kenneth, L.E.E.C. Eagleton, A. Acrivos, Pore and Solid-Diffusion Kinetics in Fixed-Bed Adsorption under Constant-Pattern Conditions., Eng. Chem. Fundamen. (1966). https://doi.org/https://doi.org/10.1021/i160018a011.
- [5] S. Lagergren, Zur theorie der sogenannten adsorption gel ster stoffe (About the theory of so-called adsorption of soluble substances), K. Sven. Vetenskapsakademiens. Handlingar. (1898).
- Y.. Ho, G. McKay, Pseudo-second order model for sorption processes, Process Biochem. 34 (1999) 451–465. https://doi.org/10.1016/S0032-9592(98)00112-5.
- [7] W. Weber, Kinetics of Adsorption on Carbon from Solution, J. Sanit. Eng. Div. (1963).
- [8] H.N. Tran, S.J. You, A. Hosseini-Bandegharaei, H.P. Chao, Mistakes and inconsistencies regarding adsorption of contaminants from aqueous solutions: A critical review, Water Res. (2017). https://doi.org/10.1016/j.watres.2017.04.014.
- [9] E.C. Lima, A. Hosseini-Bandegharaei, J.C. Moreno-Piraján, I. Anastopoulos, A critical review of the estimation of the thermodynamic parameters on adsorption equilibria. Wrong use of equilibrium constant in the Van't Hoof equation for calculation of thermodynamic parameters of adsorption, J. Mol. Liq. 273 (2019) 425–434. https://doi.org/10.1016/j.molliq.2018.10.048.