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VALORIZATION OF SPENT COFFEE GROUNDS INTO CARBON-BASED ADSORBENTS FOR CRYSTAL VIOLET REMOVAL FROM WATER

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ABSTRACT

Spent coffee grounds represent an abundant food-related waste material that can be converted into value-added carbon-based materials for environmental applications. In this study, two carbon adsorbents prepared from spent coffee grounds were evaluated for the removal of crystal violet (CV) from water. The prepared materials were characterized by SEM and BET analysis, while CV adsorption was investigated in batch mode. The maximum adsorption capacities were 360 and 374 mg g^{-1}, confirming the high efficiency of both materials. These results indicate that spent coffee grounds can be efficiently valorized as low-cost precursors for sustainable adsorbents for the treatment of dye-contaminated water.

INTRODUCTION

Crystal violet is a synthetic cationic dye whose release into wastewater may cause environmental concern due to its persistence, strong coloration, and potential toxicity [1]. Adsorption represents an efficient and environmentally suitable strategy for dye removal, particularly when low-cost carbon-based materials are used as adsorbents [2]. In this study, spent coffee grounds were valorized as a biomass precursor for the preparation of two carbon-based adsorbents and evaluated for the removal of CV from water, highlighting the potential of food waste-derived materials for sustainable water remediation.

EXPERIMENTAL

Spent coffee grounds (100% Arabica) were collected from the coffee machine at the Wood K plus office in Linz. Half of the sample was additionally extracted in boiling water for 1 h, filtered and washed three times with boiling water. Both samples were dried for 24 h at 105 °C. Afterwards the samples were carbonized in a GERO HTK8 chamber furnace at 900 °C in N_2 atmosphere (200 L h^{-1}) using the following program: 10 °C min^{-1} up to 200 °C – 1 °C min^{-1} up to 600 °C – 10 °C min^{-1} up to 900 °C – 30 min isothermal at 900 °C. For each carbonized sample, 10 g were subsequently activated in a Nabertherm RSR rotary tube furnace at 870 °C for 60 min using a CO_2 flow of 80 L h^{-1}. The activated carbons were denoted as "SCG_a60" and "wSCG_a60" for the sample from the original SCG and the washed one, respectively.

The prepared materials were characterized by scanning electron microscopy (SEM). Nitrogen adsorption–desorption measurements were performed, and the specific surface area was calculated by the Brunauer-Emmett-Teller (BET) method.

CV adsorption was investigated in batch mode using deionized water for solution preparation. Experiments were performed at pH 7, 25 °C, with an adsorbent concentration of 1 mg mL^{-1} and a contact time varied from 1 to 1440 min. After adsorption, the suspensions were centrifuged, and the residual CV concentration was determined by UV-*Vis* spectrophotometry. Control experiments were performed without adsorbent, while removal efficiency and adsorption capacity were calculated according to Uptake = 100% × $(C_o - C_{eq})/C_o$, where C_o represents the initial CV concentration, and C_{eq} corresponds to the equilibrium concentration.

RESULTS AND DISCUSSION

SEM micrographs showed irregular, porous, and fragmented carbonaceous structures for both samples, with visible surface roughness and cavities that may contribute to the accessibility of adsorption sites for CV removal.

The specific surface area of the prepared materials, determined by the BET method, was 436 m^2 g^{-1} for sample SCG_a60 and 525 m^2 g^{-1} for sample wSCG_a60, confirming that both materials possessed a well-developed porous structure, with sample wSCG_a60 showing a slightly higher surface area.

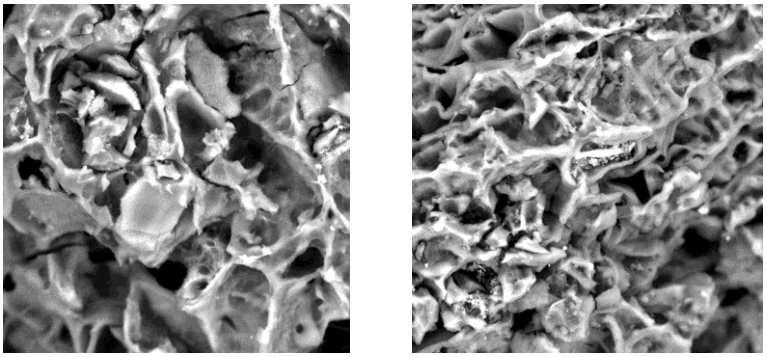


Figure 1. SEM micrographs of SCG_a60 (left) and wSCG_a60 (right)

The adsorption behavior of CV on the prepared carbon materials was further evaluated using kinetic and isotherm models to assess adsorption rate, model fit, and maximum adsorption capacity. Non-linear pseudo-first-order (PFO) and pseudo-second-order (PSO) models were used. For both materials, the PSO model provided a slightly better fit (Table 1), suggesting that both adsorbents exhibited similar kinetic behavior, with sample wSCG_a60 exhibiting a slightly higher calculated q_e value. The time of equilibrium was determined as 1440 min. The adsorption isotherms were fitted using the Freundlich and Langmuir models (Table 2), with the Langmuir model showing better agreement with the experimental data. The maximum adsorption capacities were 360 mg g^{-1} for sample SCG_a60 and 374 mg g^{-1} for sample wSCG_a60, confirming the high efficiency of both materials toward CV. The somewhat better performance of sample wSCG_a60 is consistent with its higher specific surface area.

Table 1. Kinetic parameters of CV (5×10^{-6} mol dm^{-3}) adsorption on investigated materials (1 mg mL^{-1}) at 25 °C

Material	PFO			
	q_e (mg g^{-1})	k_1 (min^{-1})	χ^2	R^2
SCG_a60	1.793	0.032	0.026	0.940
wSCG_a60	1.883	0.045	0.023	0.948
	PSO			
	q_e (mg g^{-1})	k_2 (mg min^{-1} g^{-1})	χ^2	R^2
SCG_a60	1.879	0.024	0.015	0.965
wSCG_a60	1.958	0.036	0.018	0.960

Table 2. Parameters of the Freundlich and Langmuir isotherm models for CV adsorption at an adsorbent dose of 1 mg mL^{-1}

Material	Freundlich isotherm			
	K_F ($(dm^3\ mg^{-1})^{1/n}$)	n	χ^2	R^2
SCG_a60	53.483	2.734	2681.795	0.856
wSCG_a60	34.808	2.272	683.154	0.960
	Langmuir isotherm			
	K_L ($dm^3\ mg^{-1}$)	q_{max} (mg g^{-1})	χ^2	R^2
SCG_a60	0.078	359.935	671.074	0.964
wSCG_a60	0.034	373.634	20.699	0.999

CONCLUSION

Spent coffee grounds were successfully converted into carbon-based adsorbents for the removal of CV from water. Both materials showed high adsorption capacities, while sample wSCG_a60 exhibited slightly better performance, consistent with its higher specific surface area. These results highlight spent coffee grounds as a promising, low-cost precursor for sustainable adsorbents for the remediation of dye-contaminated water.

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