Sewage sludge derived biochar accelerates toluene removal by *Pseudomonas plecoglossicida*

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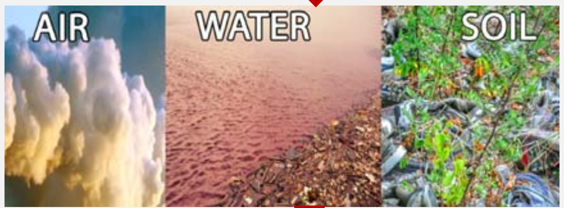
BACKGROUND

Chlorinated solvents

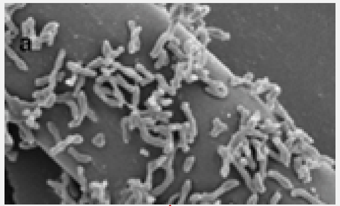
Petroleum hydrocarbons



Processes:
Chemical
Physical
Biological

VOLATILE ORGANIC COMPOUNDS (VOCs)

Toxic
Hazardous
Mutagenic
Teratogenic
Carcinogenic

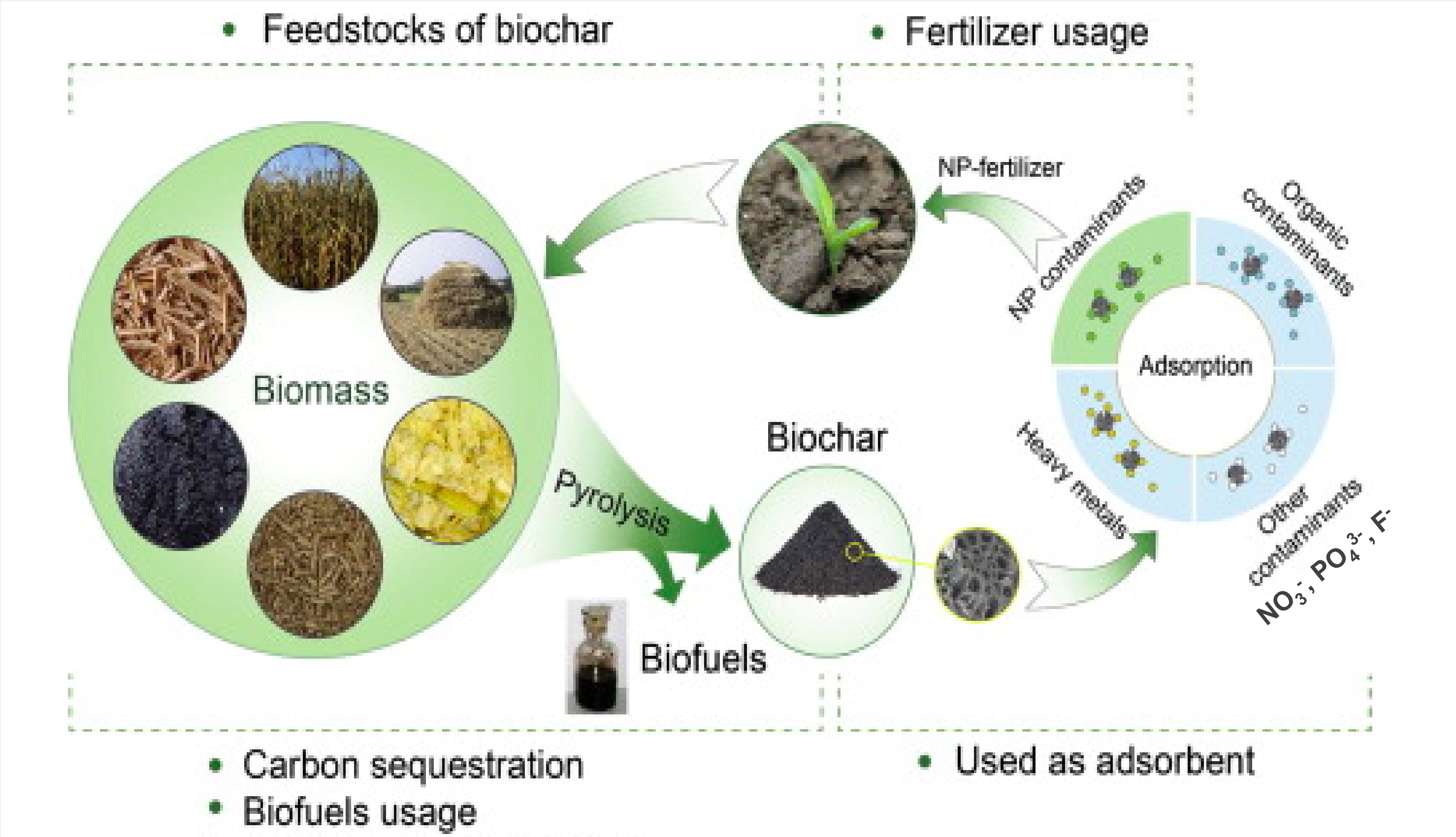


Environmentally friendly
Cost-effective nature

Microbial immobilization

- Protection from harsh environment
- Enhancing microbial activity

Biochar application



Biochar applied as an effective adsorbent for wastewater treatment

Tan, X., Liu, Y., Zeng, G., Wang, X., Hu, X., Gu, Y., Yang, Z. 2015. Application of biochar for the removal of pollutants from aqueous solutions. Chemosphere 125, 70-85.

OBJECTIVES

- ✓ To evaluate the role of sewage sludge-based biochar, generated at different pyrolysis temperatures (300°C, 500°C, and 700°C), on the biological removal of toluene, a model VOC, by *Pseudomonas plecoglossicida*.
- ✓ To further evaluate the effects of deashed biochar and leaching biochar solution on toluene bioremoval performance, whether accelerating toluene mineralization.

EXPERIMENTAL

- ✓ Sewage sludge: From local wastewater treatment plant; Dried (80°C overnight), crushed, and sieved.

Sludge based biochar

Pyrolysis
4 h (5°C min^{-1})
300°C, 500°C, and 700°C

BC_{300}, BC_{500}, and BC_{700}

BC_{500}

Washed with HCl (1 M) and HF (1 M)
Rinsed with water
Dried (80°C overnight)

Deashed biochar (DA-BC_{500})

BC_{500}

50 mg BC_{500}
45 mL MSM
Nitrogen 10 min
Shaken 3 days
Filtered

Leaching biochar solution

- ✓ *Pseudomonas plecoglossicida* previously isolated from a petroleum contaminated site in Xiamen (China) and subcultured in MSM (pH 7) containing (g/L): KH_2PO_4 1.0; K_2HPO_4 1.0; NH_4NO_3 1.0; $MgSO_4{\cdot}7H_2O$ 0.2; $Fe_2(SO_4)_3$ 0.05; $CaCl_2$ 0.02; and toluene (150 mg/L)

Microcosms:

Serum bottles: MSM (mineral salts medium) solution (45 mL)
Toluene (250 mg/L)
Inoculum (5 mL)
Biochar (BC_{300}, BC_{500}, BC_{700}, DA-BC_{500} ; 50 mg)

Incubation: 150 rpm , 30°C, pH 7, 3 days

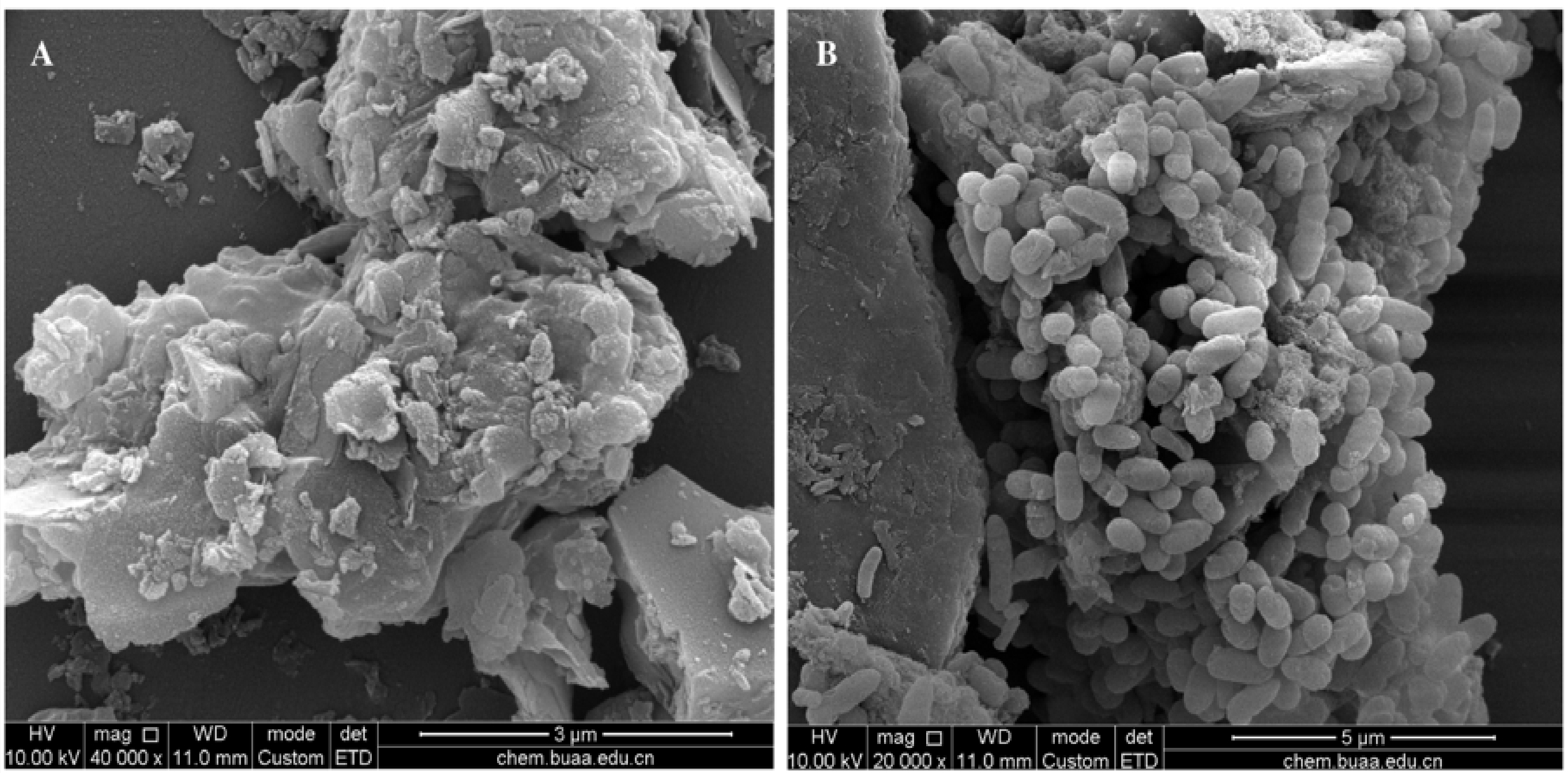
- ✓ Liquid samples collected daily to analyze toluene residual concentration (GC-FID)
- ✓ Microcosms without inoculum set as control (abiotic losses)
- ✓ Toluene adsorption capacity (q_e) on different biochars assessed at different times (5, 24, 48, and 72 h)
- ✓ Langmuir and Freundlich isotherm models for toluene (20, 50, 100, 200, and 300 mg/L) on 50 mg biochar (BC_{500}) in 50 mL MSM solution

RESULTS

Some physicochemical parameters of biochars

Biochar	pH	Dv (50) µm	Extractable TP (mg/g BC)	Extractable COD (mg/g BC)	Extractable TN (mg/g BC)
BC_{300}	7.2	77.3	0.43	2.13	0.29
BC_{500}	9.5	61.4	0.27	0.07	0.02
BC_{700}	10.8	59.2	0.07	0.10	0.007
DA-BC_{500}	3.2	72.9	0.13	0.17	0.16

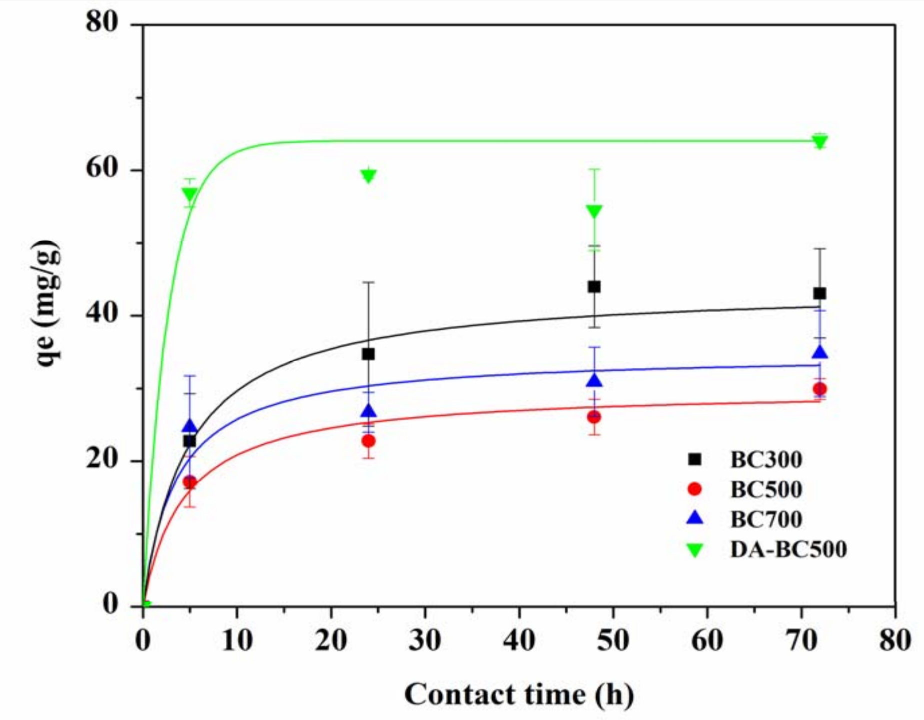
- ✓ pH significantly increased when higher pyrolysis temperatures applied ($p<0.05$)
- ✓ Deashing treatment with a significant impact on the biochar fine portion, compared to the thermal treatment only; Fine particle portion of biochar decreasing with increasing temperatures
- ✓ Extractable TP, COD, and TN higher for the biochar produced at lower pyrolysis temperature (300°C)



SEM micrographs for (A) biochar (BC_{500}) (x40,000) and (B) biochar (BC_{500}) with *Pseudomonas* sp. attached on its surface (x20,000)

- ✓ **Surface morphology coarse and heterogeneous**
- ✓ **Rough aggregated micrometric structures with irregular size and orientations**
- ✓ ***Pseudomonas* sp. colonized the biochar surface efficiently**

Adsorption kinetics



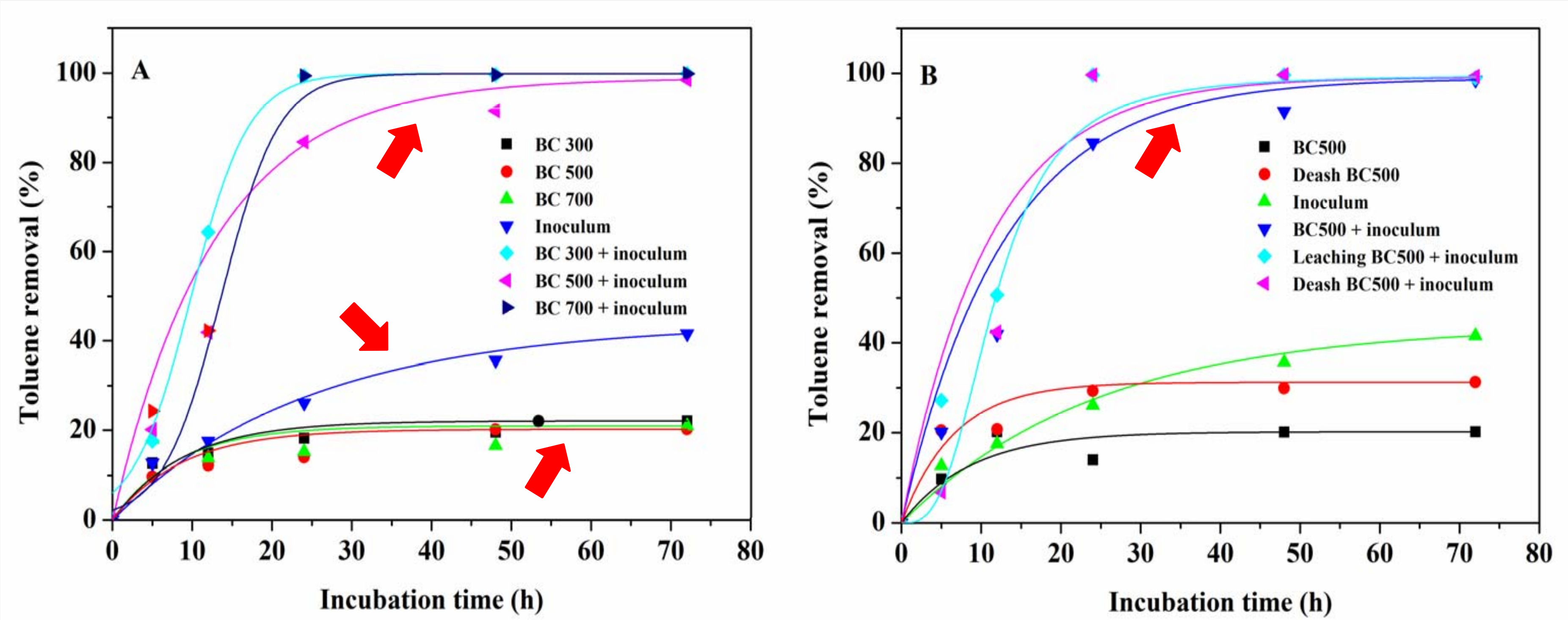
Toluene (250 mg/L) adsorption capacity (q_e) on different (BC_{300}, BC_{500}, BC_{700}, DA-BC_{500}) biochars (50 mg)

- ✓ Highest adsorption capacity on deashed biochar (64.1±0.9 mg/g) ($p<0.05$)
- ✓ Removal of the inorganic fraction (ash) might have created additional sorption sites on its surface
- ✓ Main purpose of biochar addition, to enhance toluene bioremoval (through biosorption)
- ✓ BC500: Showing the lowest toluene adsorption capacity, used to generate deashed biochar and leaching biochar solution

Adsorbent	Langmuir			Freundlich		
	C_m (mg/g)	K_L (L/mg)	r^2	K_f (mg/g) $(L/mg)^{1/n}$	1/n	r^2
Biochar (BC_{500})	**3.28**	**0.005**	**0.60**	**0.002**	**1.80**	**0.99**

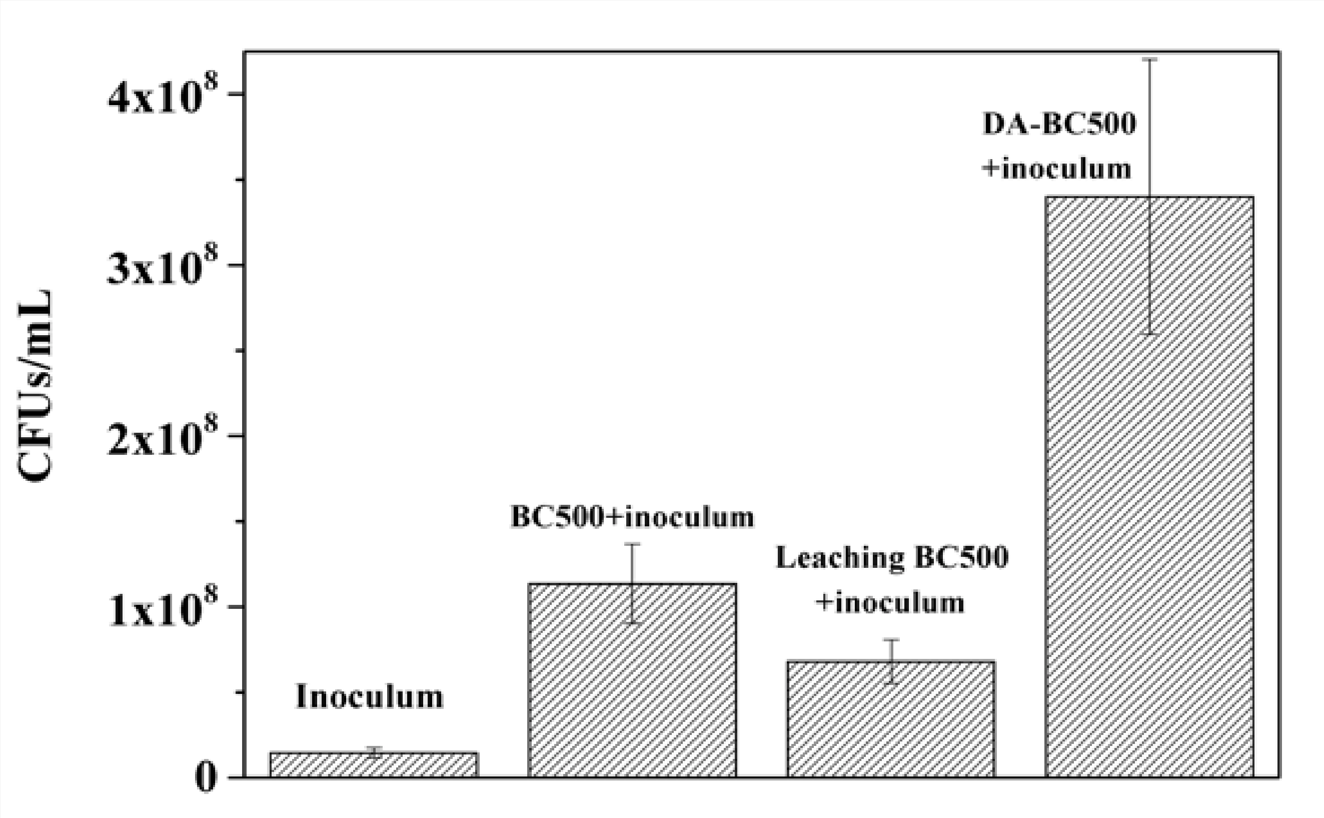
- ✓ Freundlich isotherm showed a better fit ($r^2 = 0.99$) to the adsorption data
- ✓ Biochar surface is heterogeneous with adsorption sites of different affinities

Biological removal of toluene and role of biochar



Toluene removal efficiency of *Pseudomonas* sp.: (A) with biochar produced under different temperatures (BC_{300}, BC_{500}, and BC_{700}) and (B) with BC_{500}, deashed BC_{500}, BC_{500} leaching solution

Microbial growth in the presence of biochar



Colony forming units (CFUs) for the microcosms with inoculum only and with inoculum + biochars

- ✓ **Removal of ash from biochar exposing additional surface area, mainly small-diameter pores, favoring the inoculum colonization and proliferation**

CONCLUSIONS

- ✓ The biological and sorption removal of toluene were not that effective when isolate and biochars (BC_{300}, BC_{500}, and BC_{700}) applied alone. However, when biochar applied together with inoculum, toluene was almost completely removed after 2 days (through biosorption).

- ✓ Biochar promoted the microbial immobilization on its surface and substantially enhanced/facilitated the toluene bioremoval compared to the system with the microbial isolate only.

- ✓ Biochar could be considered an efficient electron mediator, and its redox moieties could essentially influence the electron transfer between microbial cells and toluene, with both sorbed on the biochar particles.

- ✓ The developed hybrid (physical/sorption + biological/immobilization) process as a promising technology considering the biochar as ecofriendly nature waste with special redox characteristics.

FUTURE WORKS

- Further studies warranted to further clarify the mechanism of toluene removal in the presence of biochar and what kind of compounds (organics and/or inorganics) stimulating the microbial growth especially when the biochar leachate used to remove toluene efficiently.

- Long-term stability of biochar and its reutilization to be further evaluated, especially in terms of contaminants/nutrients availability and microbial immobilization.

- Application of this hybrid technology can also be extended to other VOCs commonly found in contaminated sites (subsurface environment; soil and groundwater).

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