Can Carbonaceous Particle Amendments—Including Biochar—Improve the Anaerobic Digestion of Agricultural Wastes?

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Anaerobic digestion can provide an environmentally sound approach to animal waste management

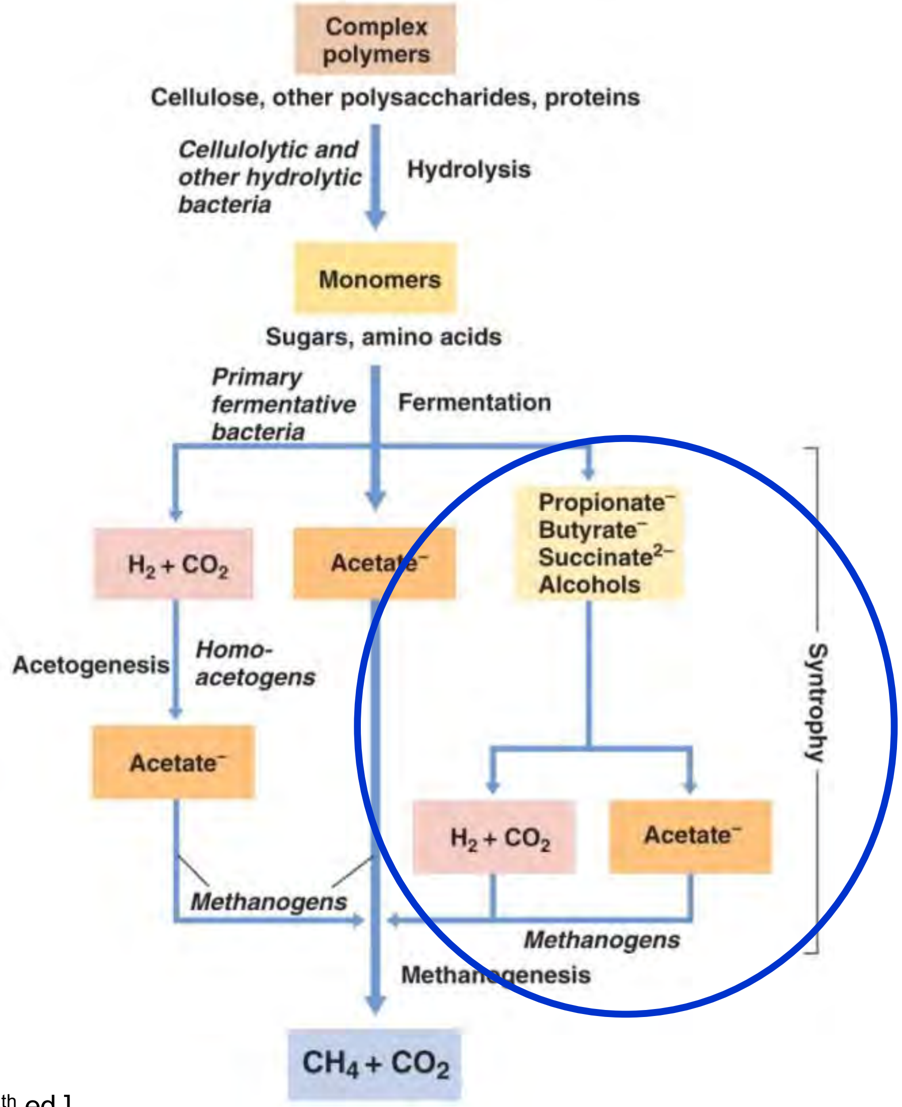
Open-air, swine lagoons

Anaerobic digesters

Anaerobic digesters face startup, stability, and economic challenges

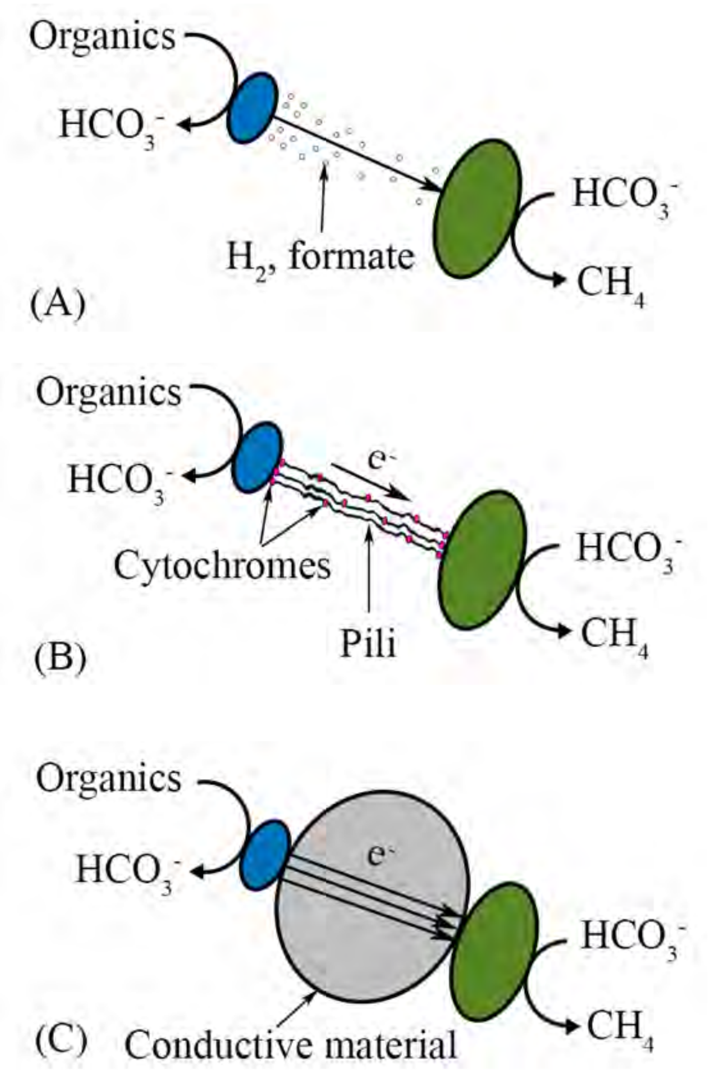
[www.newsobserver.com] [www.chemicalreport24.com]

Efficient electron transfer within anaerobic communities is critical for stable anaerobic digester operation



[Brock Biology of Microorganisms, 13th ed.]

Microbe-to-microbe electron transfer mechanisms



Mediated interspecies electron transfer (MIET)

Direct interspecies electron transfer (DIET)

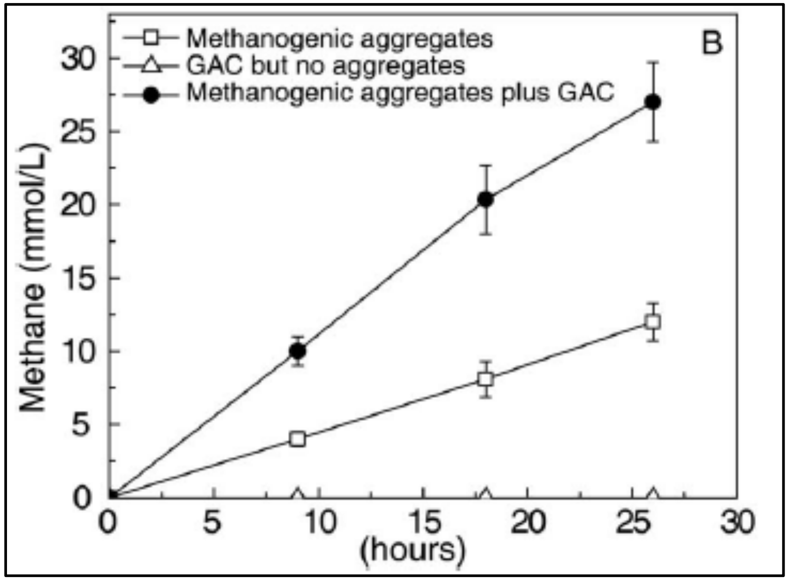
DIET via pyrogenic carbonaceous material (PCM)

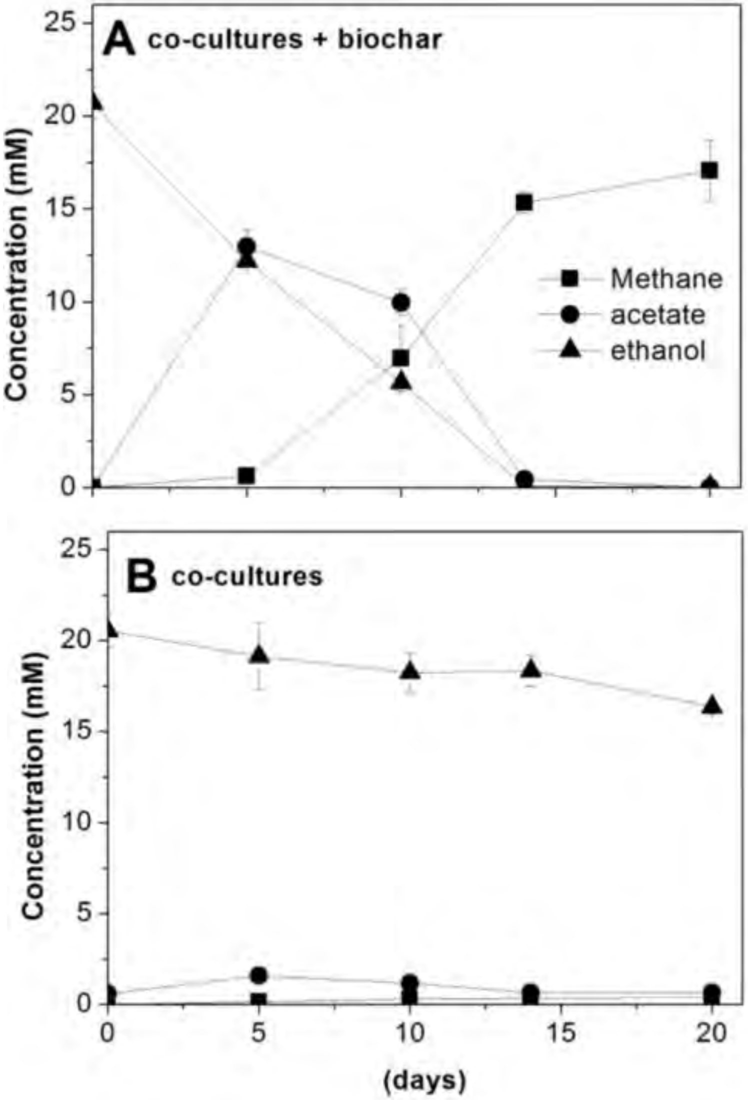
[Cheng Q. & Call D. F. , *Env. Sci. Process. Impact*, 2016]

Our understanding of DIET is primarily limited to **defined** cultures

Defined cultures

- *Geobacter metallireducens* and *Methanosarcina barkeri*
- *Geobacter metallireducens* and *Methanosaeta harundinacea*



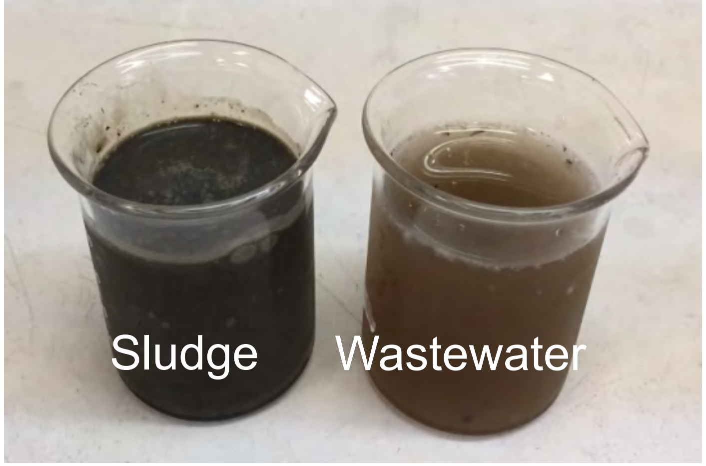


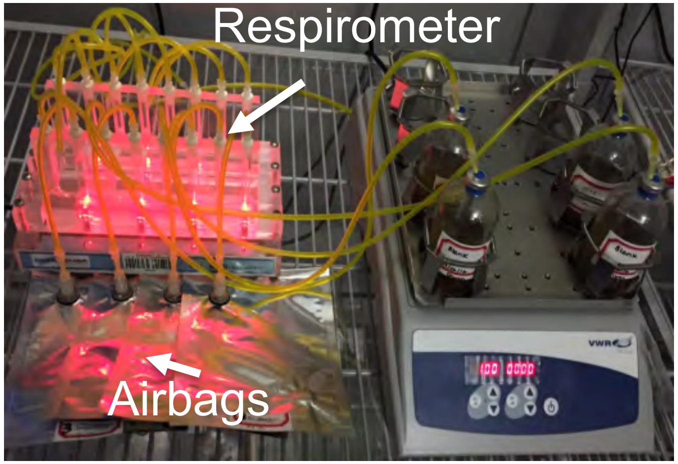
[Liu et all, *Energy Envion. Sci*., 2012] [Chen et al., *Sci. Reports*, 2014]

Objective: To determine the impact of PCM addition on the anaerobic digestion of animal wastewater

Swine wastewater properties

Parameter	Unit	Values
Total chemical oxygen demand (TCOD)	mg/L	4,800 ± 1,700
Total suspended solids (TSS)	mg/L	7,100 ± 600
Volatile suspended solids (VSS)	mg/L	4,700 ± 800
pH		7.4 ± 0.2

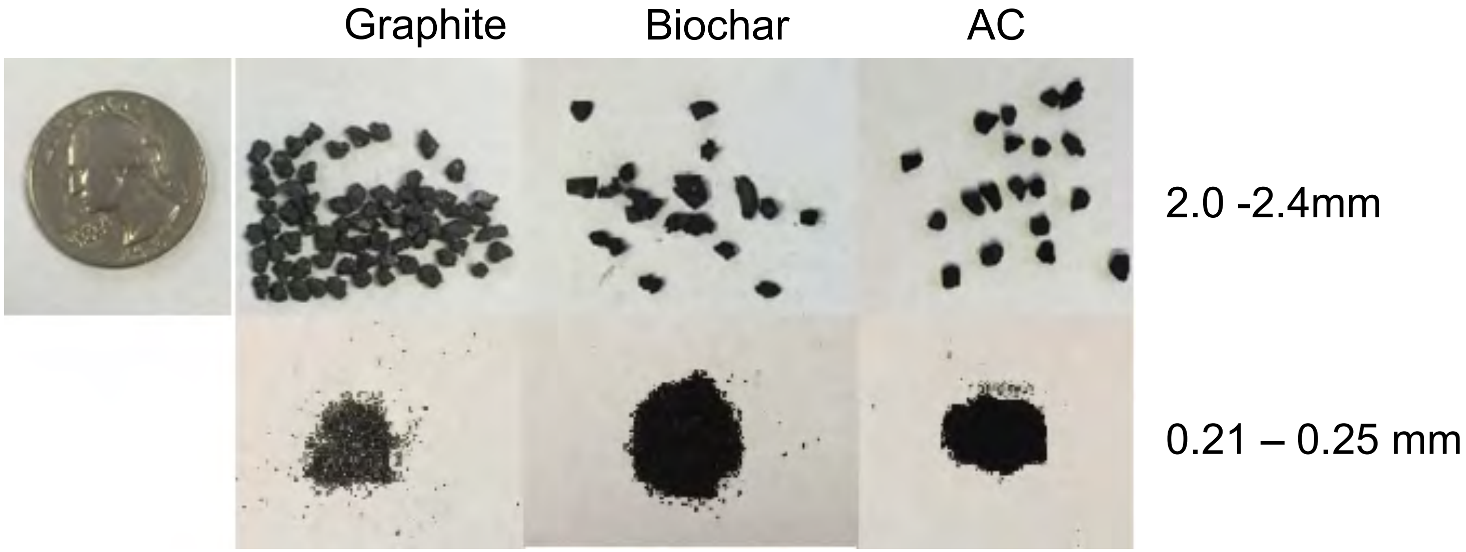




Particle properties

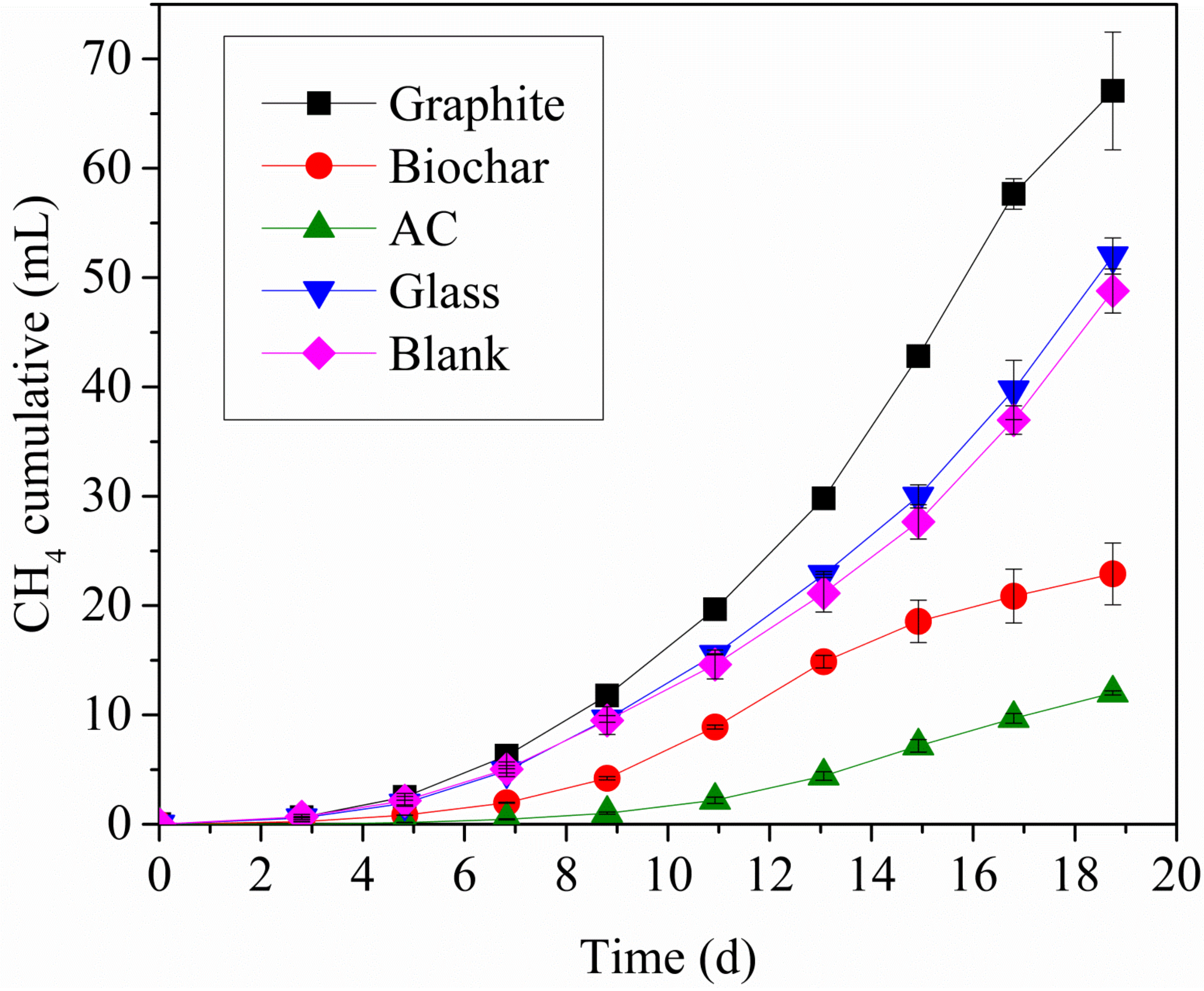
	Unit	Graphite	Biochar	AC
Conductivity	S/cm	17 ± 2.6	0.22 ± 0.046	1.2 ± 0.25
Surface area	m^2/g	0.6 - 19	15 - 209	258 – 1,596
Size	mm	2.0 - 2.4 (granule), 0.21-0.25 (powder)		
Loading	g particles /g VSS	6, 3, 1.5		

Controls
Blanks (no particles)
Glass particles



(Pierson H. O., Noyes Publications, 1993; Trammell M.P. & Pappano, P.J., Oak Ridge National Laboratory, 2011. Chen S. et al., *Sci. Rep.*, 2014; Ao G. et al., *Carbon lett.*, 2008; E. Berl, *Trans. Faraday Soc.*, 1938; Kastening B. et al., *Electrochim. Acta*, 1997; Shornikova O. N. et al., *Russ. J. Phys. Chem. A.*, 2009; Mishima D. et al., In Electrical Insulation and Dielectric Phenomena, 2011)

CH_4 generation rates were recorded in real-time to determine differences in bioreactor kinetics



<u>Sample cycle</u>

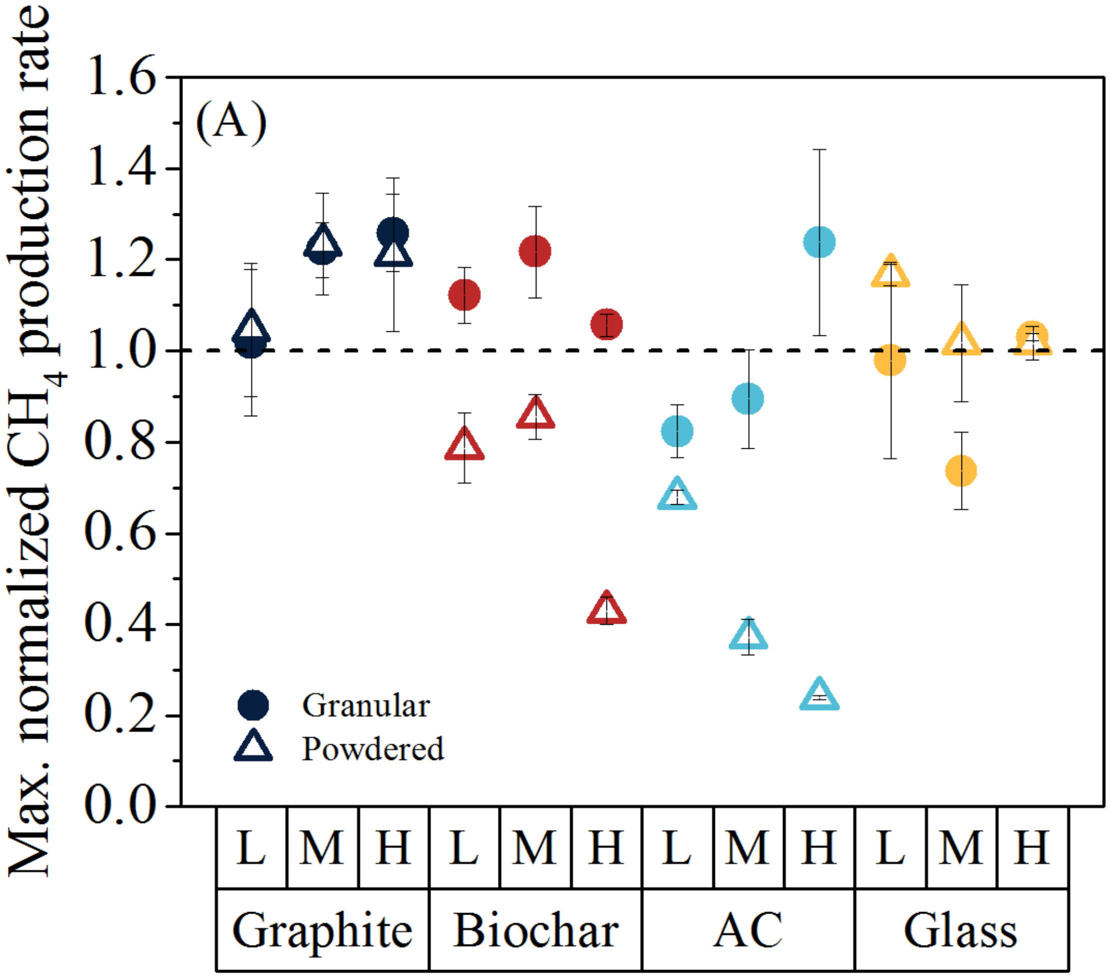
particle size:

212-250µm,

loading rate:

6 g-particles/g-VSS

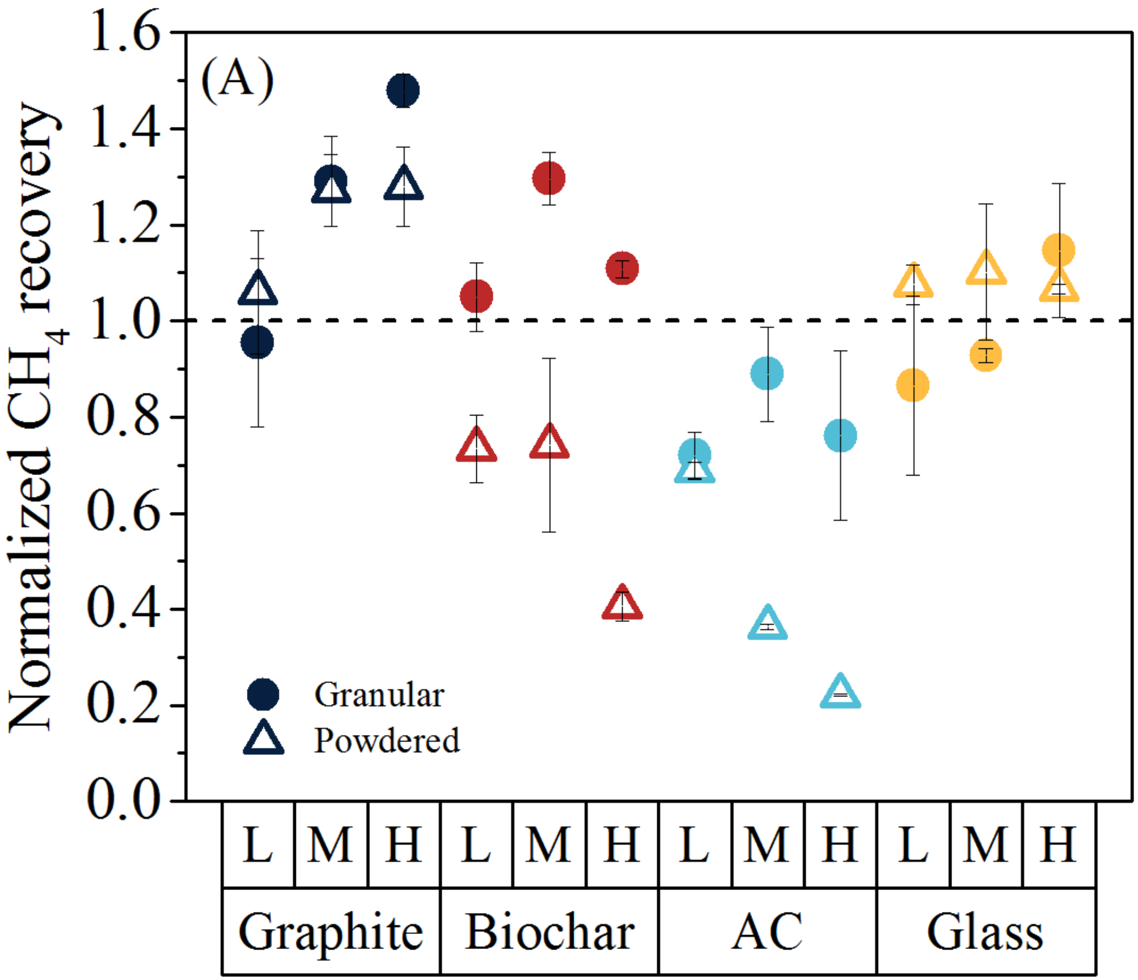
Graphite consistently resulted in higher normalized CH_4 production rates. Biochar & AC results depended on particle size



<u>Loading</u>
L – low
M – medium
H - high

[Cheng et al., *Environ. Sci. Water Res. Technol.*, In press]

CH_4 recoveries followed a similar trend, except that all AC amendments decreased CH_4 recovery relative to the control

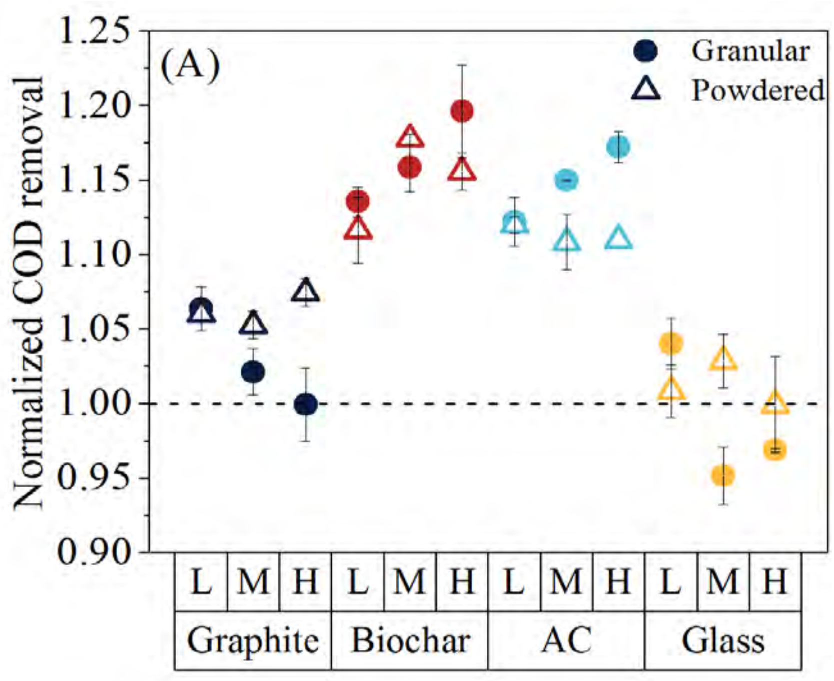


Loading
L – low
M – medium
H - high

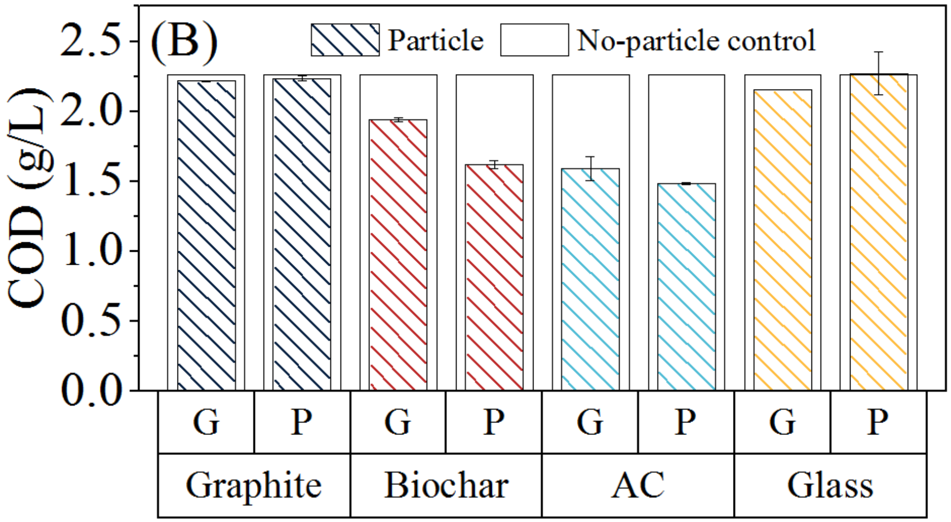
[Cheng et al., *Environ. Sci. Water Res. Technol.*, In press]

Although CH_4 recoveries were lower with biochar and AC, more COD was removed than the no-particle controls.

COD removal in bioreactors



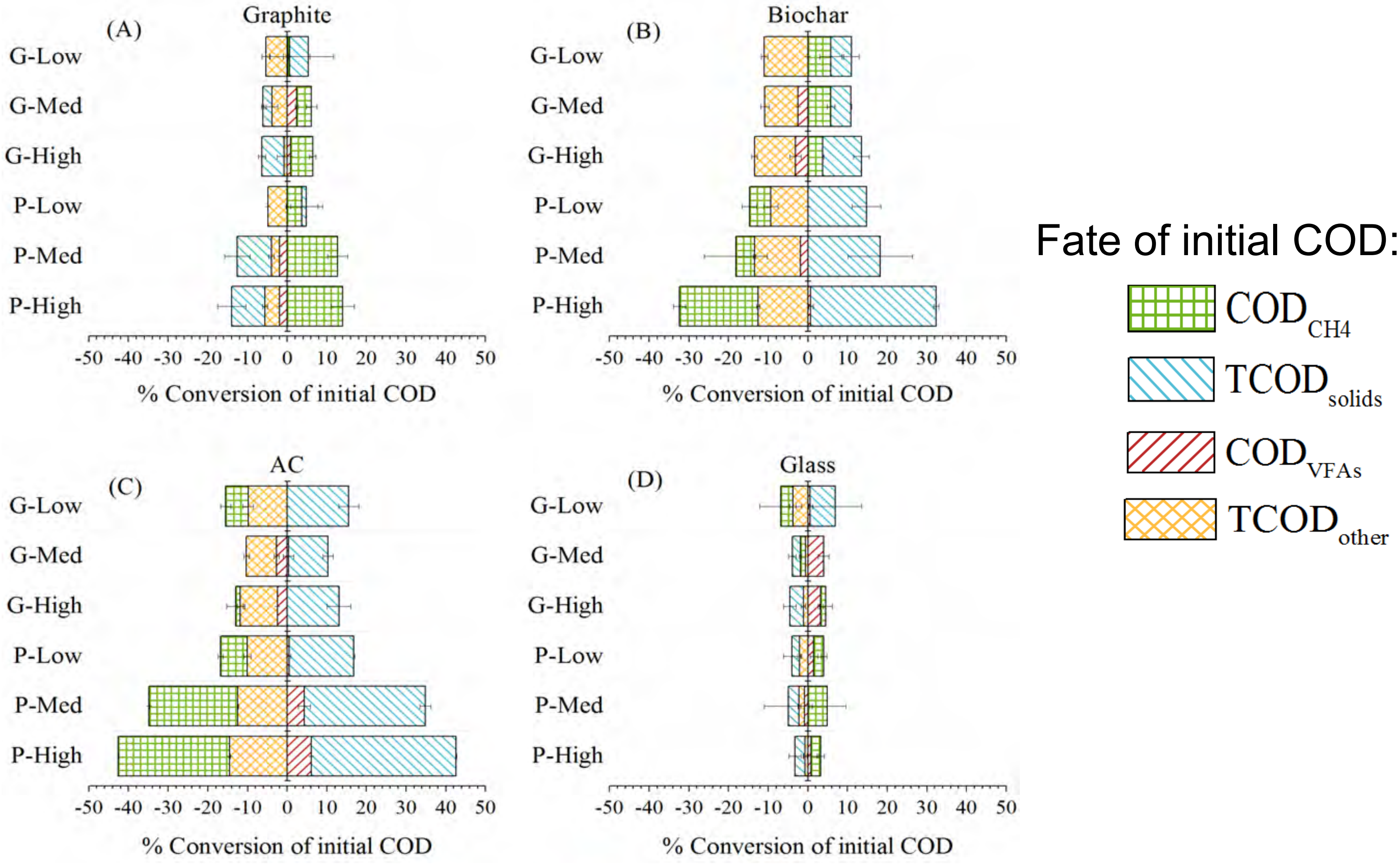
COD removal in **sterile** bioreactors



COD – chemical oxygen demand

[Cheng et al., *Environ. Sci. Water Res. Technol.*, In press]

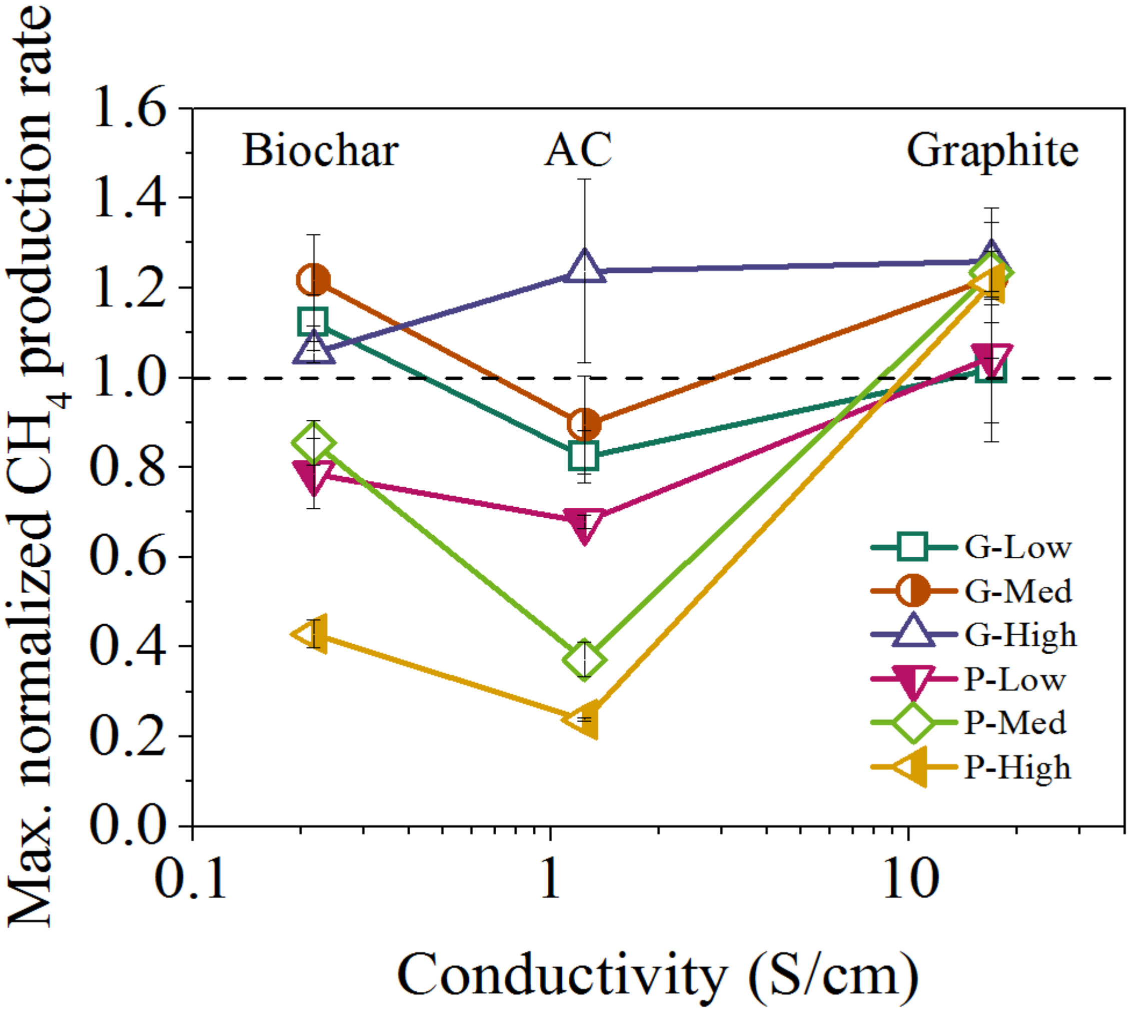
COD likely adsorbed to biochar and AC, which reduced its conversion to CH_4



Fate of initial COD:

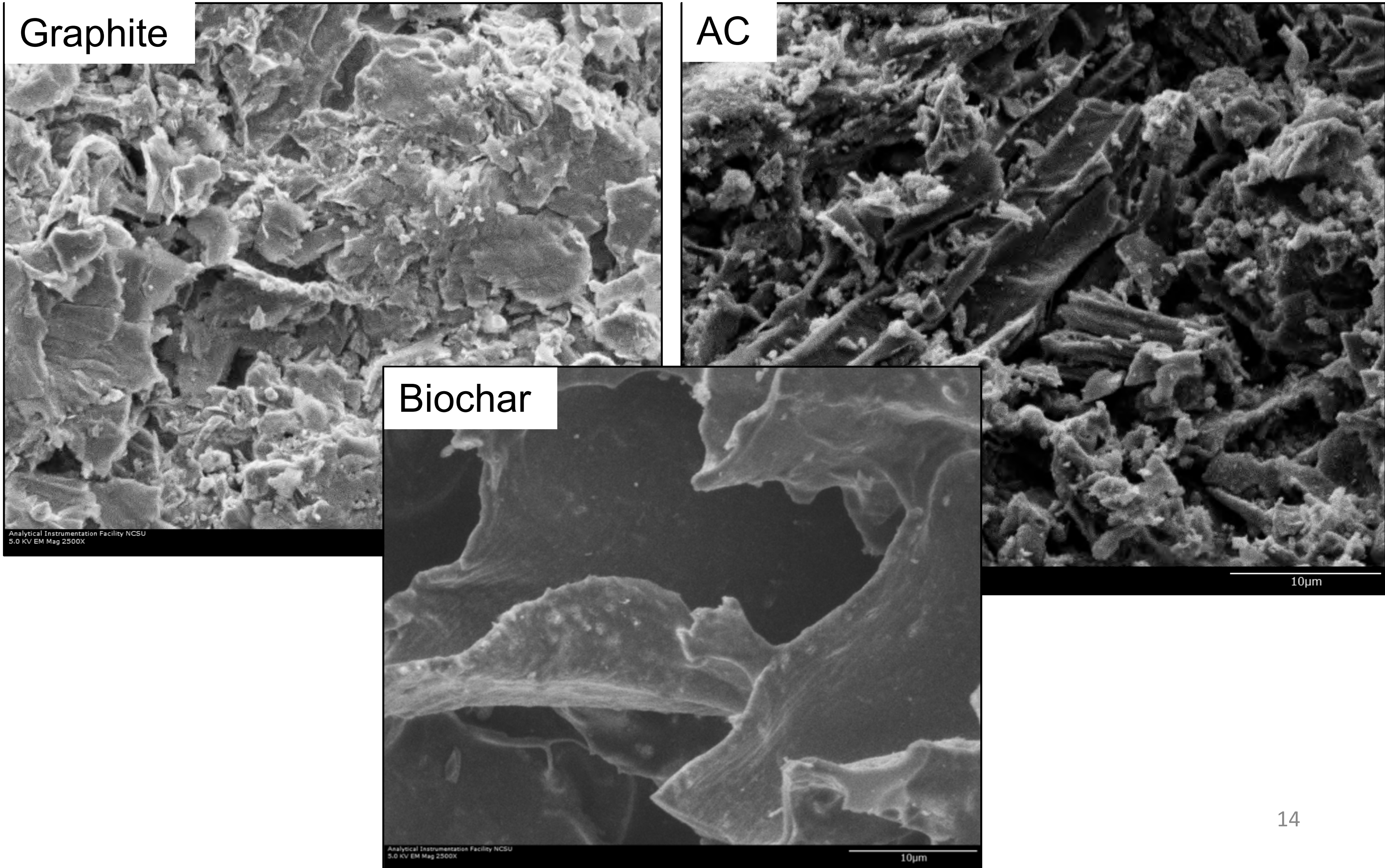
[Cheng et al., *Environ. Sci. Water Res. Technol.*, In press]

There were no clear relationships between CH_4 production and PCM electrical conductivity



[Cheng et al., *Environ. Sci. Water Res. Technol.*, In press]

Surface property structures varied across all particle types



Overall, only graphite consistently yielded larger normalized CH_4 generation rates and recoveries

- Biochar was not far behind graphite, with granular biochar yielding > 20% increase in CH_4 production rates than bioreactors without particles.
- Powdered biochar and AC amendments led to a sharp drop in CH_4 production rates
- Adsorption was the likely cause of high COD removals and low CH_4 recoveries for biochar and AC
- Economics

Graphite: \$100 - \$2,000 / ton	**\$3.36 / m^3-wastewater**
AC: \$40 - \$4,000 / ton	**\$1.34 / m^3-wastewater**
Biochar: \$0.5 - \$800 / ton	**\$0.02 / m^3-wastewater**

- We still need a better understanding of what exactly happens when biochar is added to digesters

[Cheng Q. & Call D. F. , *Env. Sci. Process. Impact*, 2016]

Acknowledgements

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Collaborator: Dr. Francis de Los Reyes

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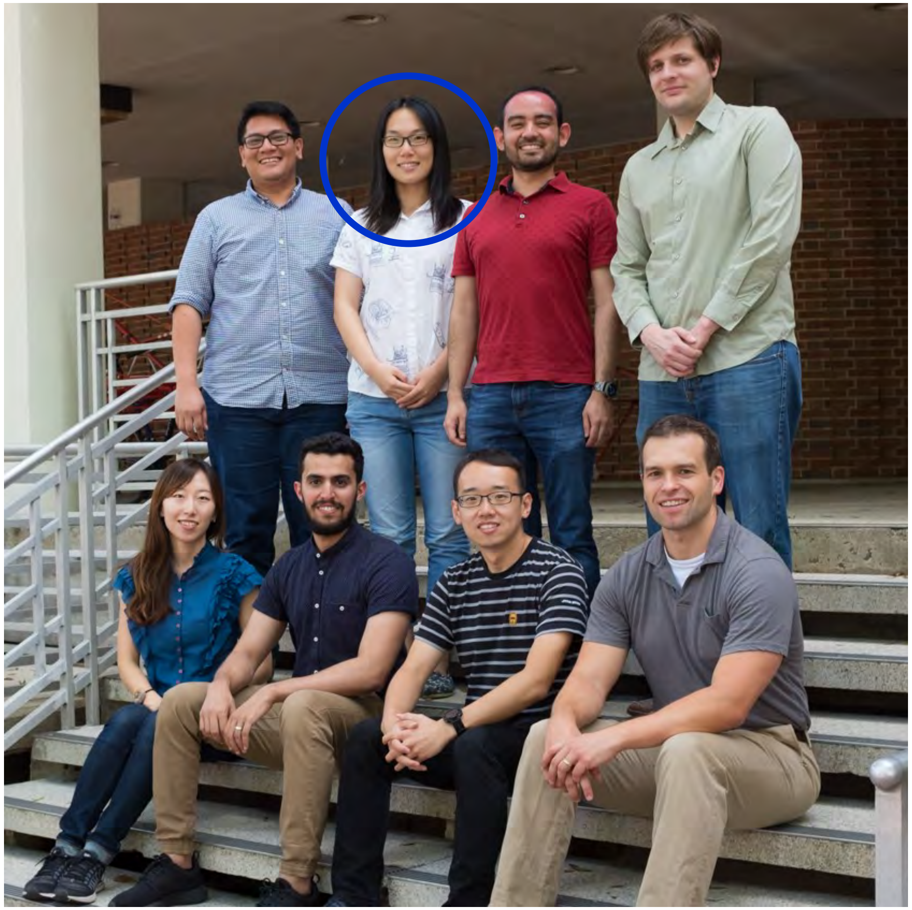
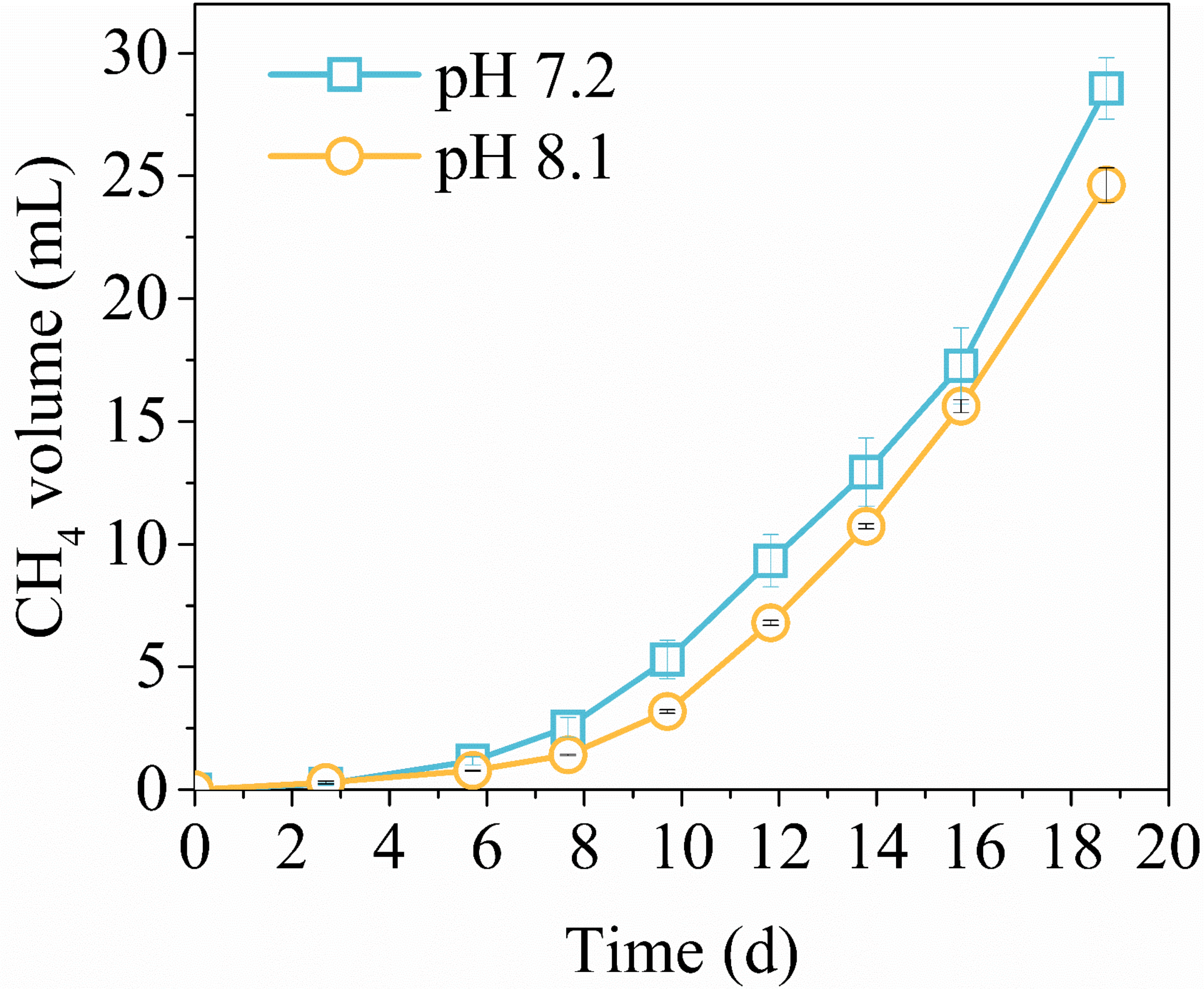
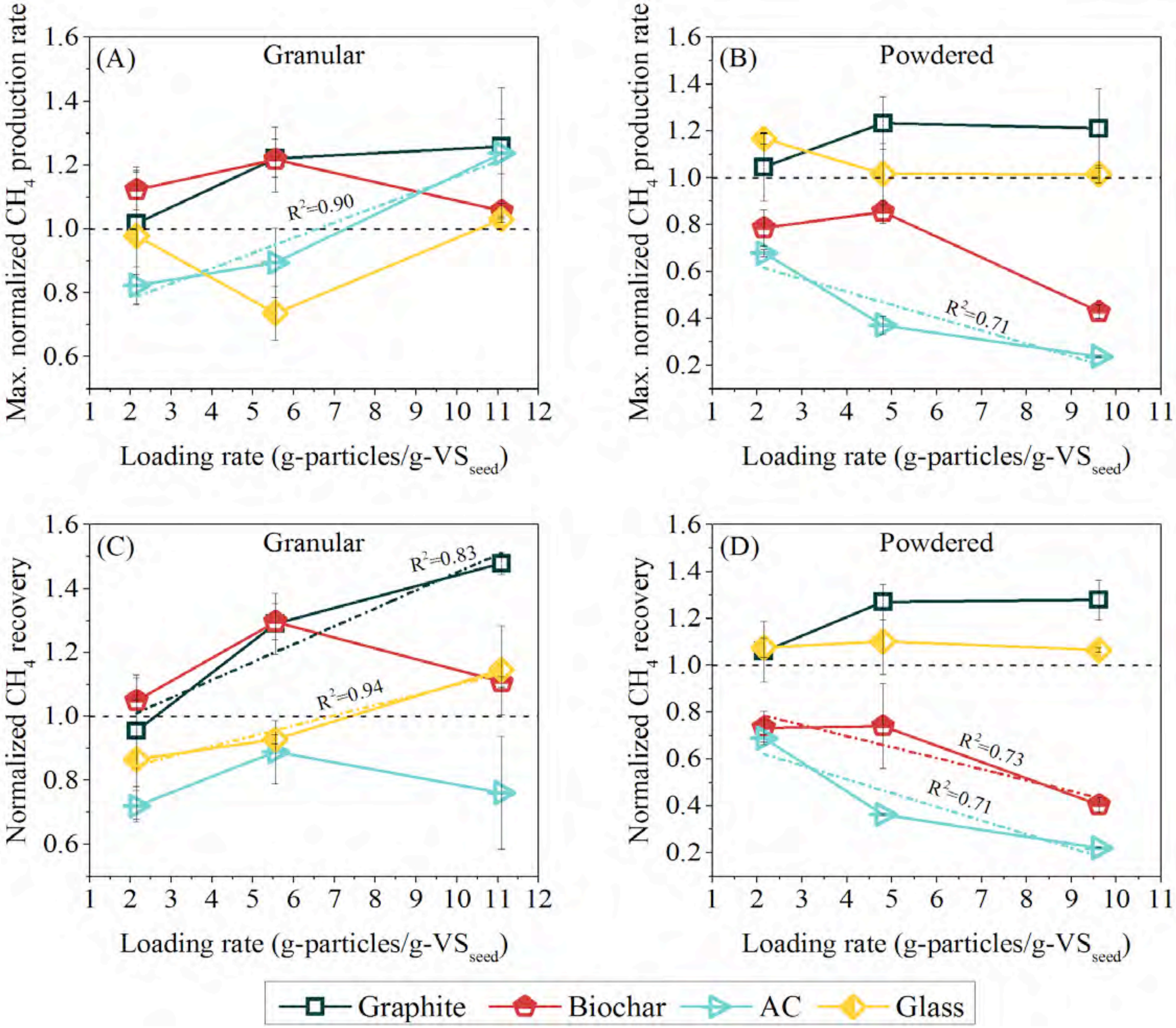
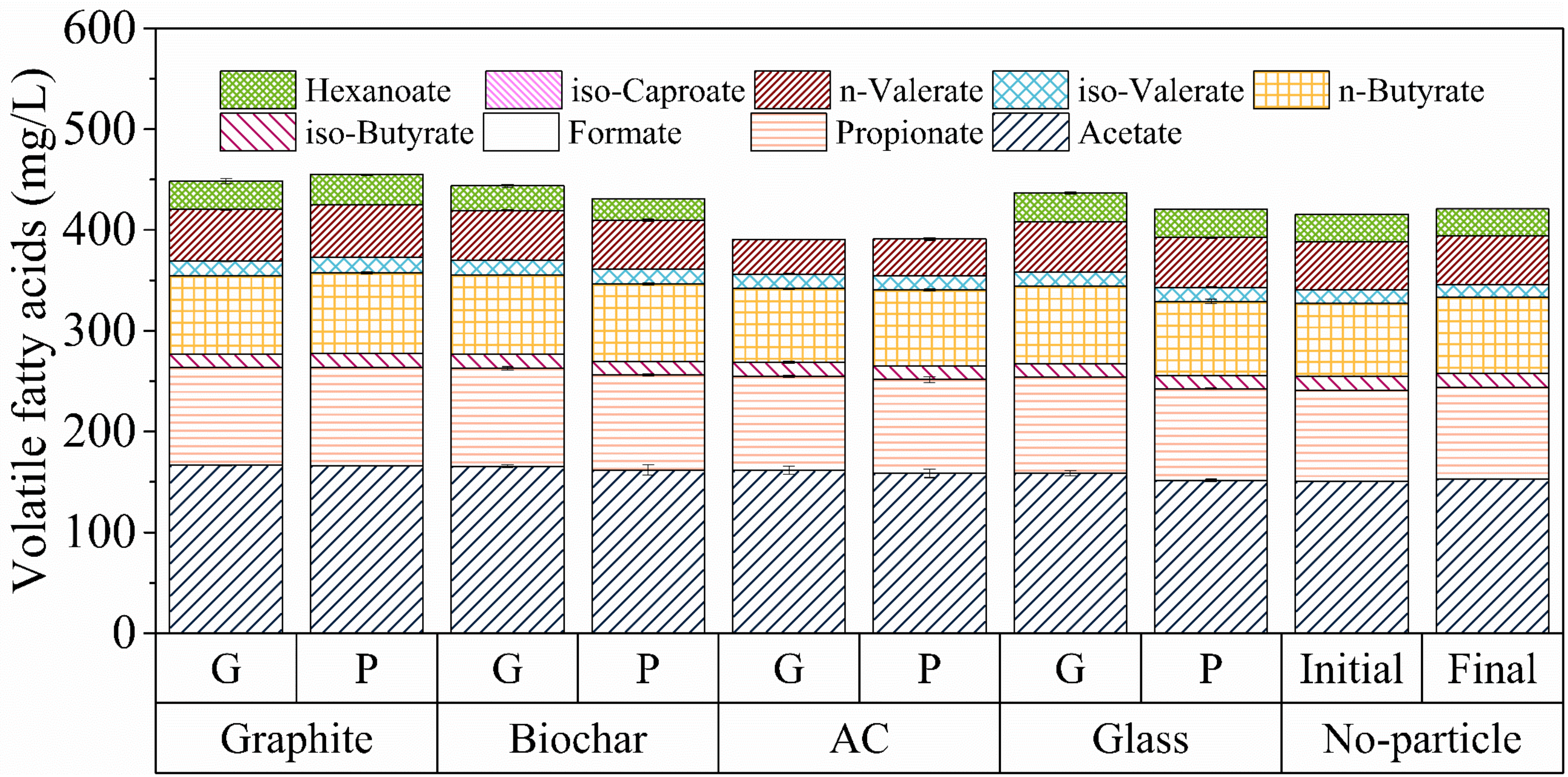
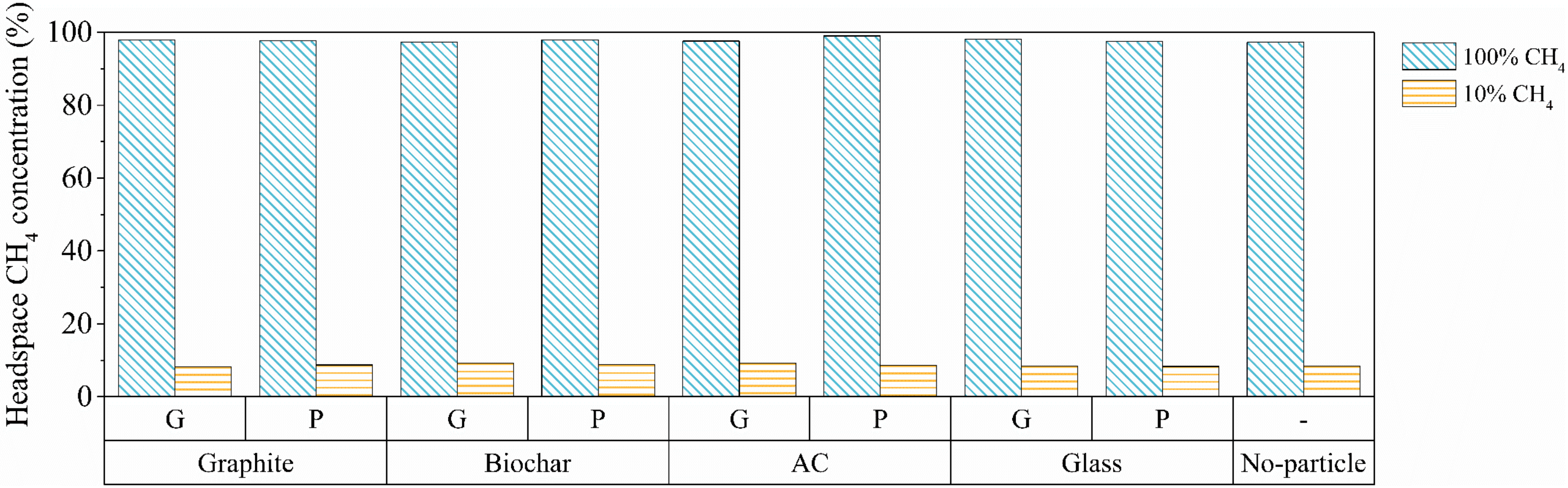
NC WATER RESOURCES RESEARCH INSTITUTE

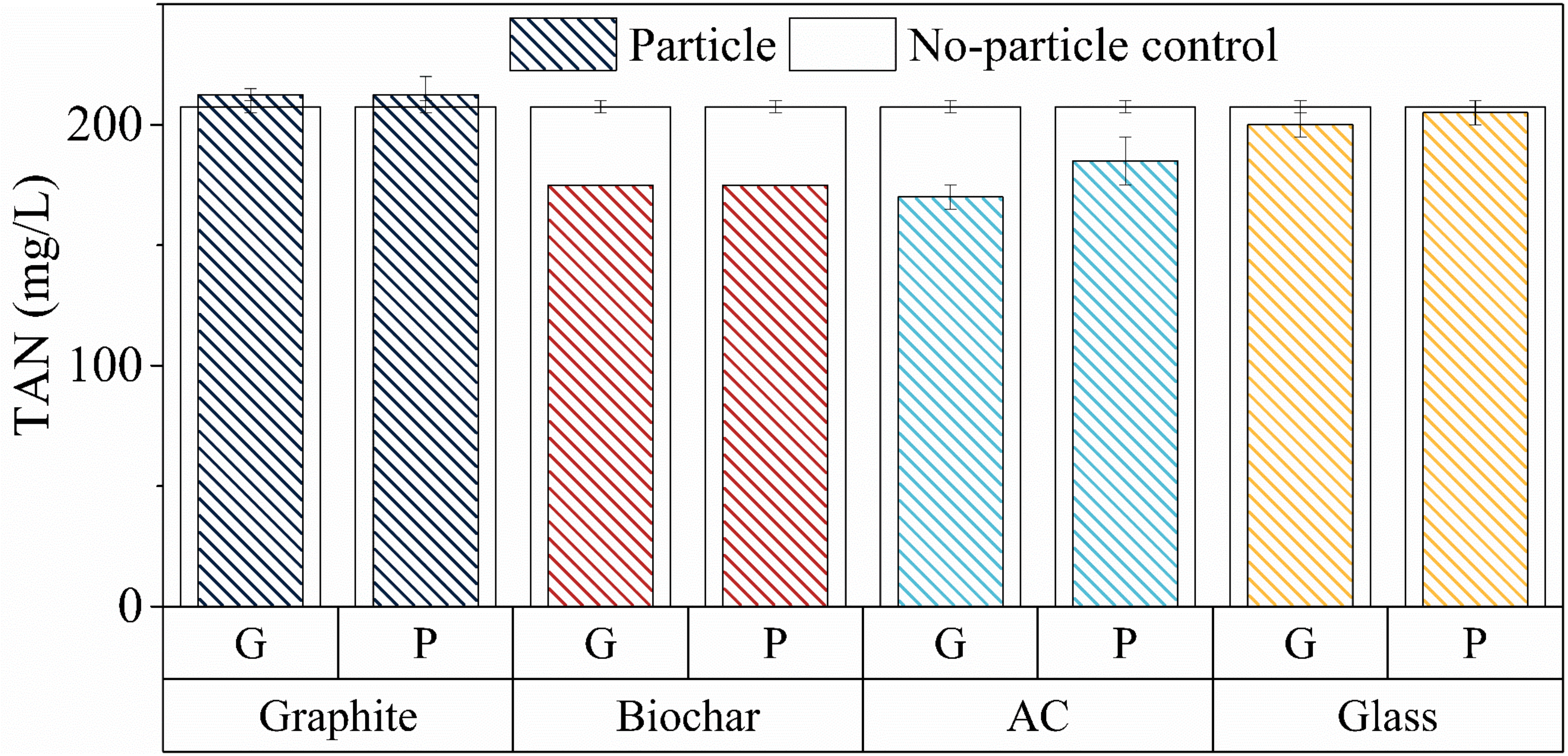


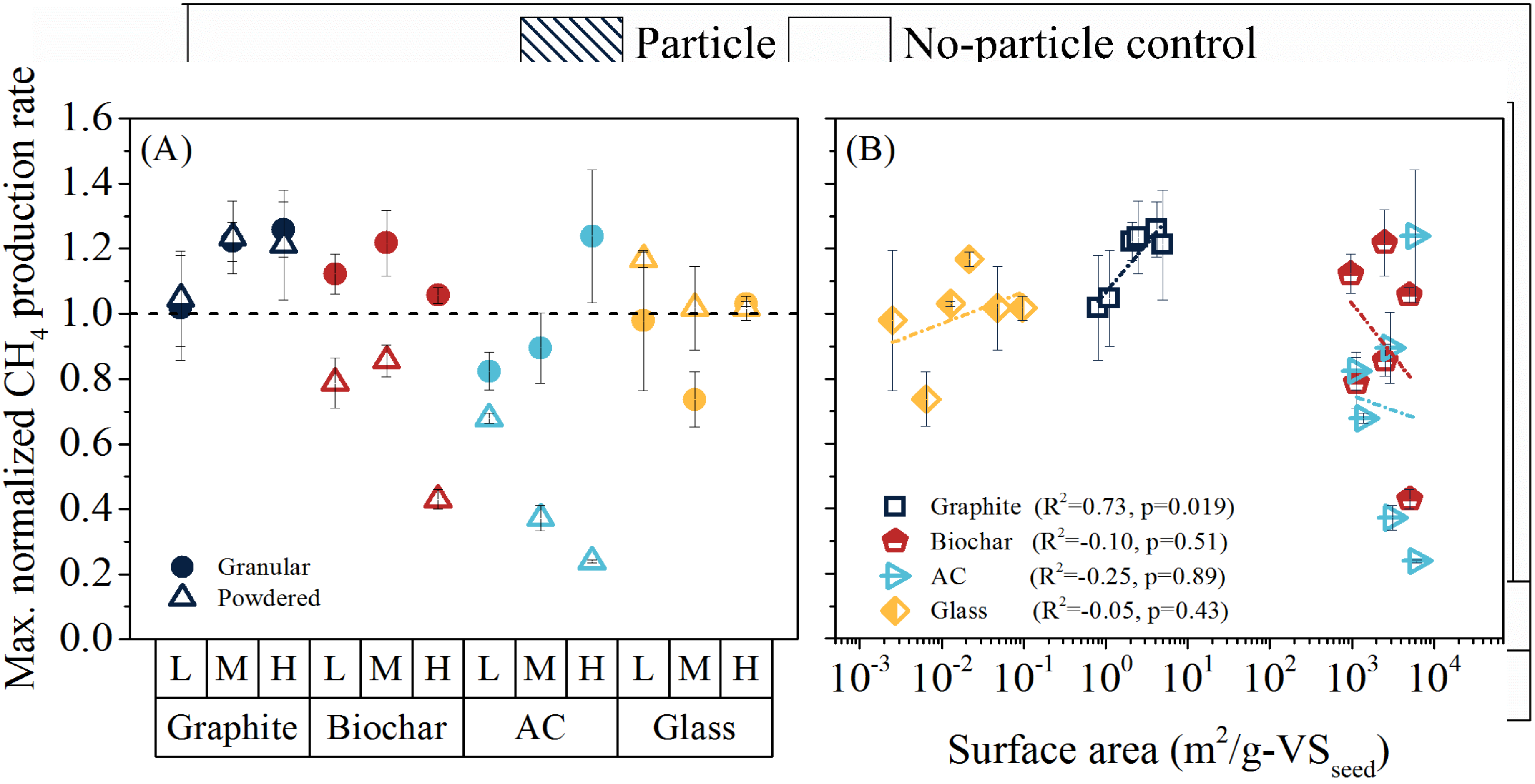

pH 7.2
pH 8.1
CH_4 volume (mL)
0
5
10
15
20
25
30
Time (d)
0
2
4
6
8
10
12
14
16
18
20


(A)
Granular
Max. normalized CH_4 production rate
1.6
1.4
1.2
1.0
0.8
0.6
R^2=0.90
1 2 3 4 5 6 7 8 9 10 11 12
Loading rate (g-particles/g-VS_{seed})
(B)
Powdered
Max. normalized CH_4 production rate
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
R^2=0.71
1 2 3 4 5 6 7 8 9 10 11
Loading rate (g-particles/g-VS_{seed})
(C)
Granular
Normalized CH_4 recovery
1.6
1.4
1.2
1.0
0.8
0.6
R^2=0.83
R^2=0.94
1 2 3 4 5 6 7 8 9 10 11 12
Loading rate (g-particles/g-VS_{seed})
(D)
Powdered
Normalized CH_4 recovery
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
R^2=0.73
R^2=0.71
1 2 3 4 5 6 7 8 9 10 11
Loading rate (g-particles/g-VS_{seed})
Graphite
Biochar
AC
Glass


Volatile fatty acids (mg/L)
0
100
200
300
400
500
600
Hexanoate
iso-Caproate
n-Valerate
iso-Valerate
n-Butyrate
iso-Butyrate
Formate
Propionate
Acetate
G
P
G
P
G
P
G
P
Initial
Final
Graphite
Biochar
AC
Glass
No-particle


Headspace CH_4 concentration (%)
100
80
60
40
20
0
G
P
G
P
G
P
G
P
-
Graphite
Biochar
AC
Glass
No-particle
100% CH_4
10% CH_4


Particle
No-particle control
TAN (mg/L)
200
100
0
G
P
G
P
G
P
G
P
Graphite
Biochar
AC
Glass


▨ Particle
☐ No-particle control
Max. normalized CH_4 production rate
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(A)
● Granular
△ Powdered
L M H L M H L M H L M H
Graphite
Biochar
AC
Glass
(B)
Graphite (R²=0.73, p=0.019)
Biochar (R²=-0.10, p=0.51)
AC (R²=-0.25, p=0.89)
Glass (R²=-0.05, p=0.43)
10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4}
Surface area (m^2/g-VS_{seed})