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Energy self-sustained treatment of swine wastewater in a microbial electrochemical technology-centered hybrid system

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The continuous stirred microbial electrochemical system (CSMES) was developed by integrating microbial electrochemical system (MES) and continuous stirred tank reactor (CSTR) into a single design. A three-phase separator was kept to maintain the advantage of CSTR, and simultaneously separated the CSMES into two zones, including the microbial electrochemical zone (MEZ) (**Fig. S1b)** and complete mixing zone (CMZ)**(Fig.S1c**). In the CMZ, continuous mixing of the activated sludge and pollutants was achieved by a micro-motor, where high rate of hydrolysis and acidification occurred and volatile fatty acids (VFAs) were harvested. A portion of the VFAs could be transferred to the MEZ, where they were further degraded for electricity generation in the anode. In addition, the removal of VFAs from the CMZ also released their inhibition on methanogens, which might enhance the methanogenesis process in CMZ.

The tide-type biocathode microbial electrochemical system (TBMES) was characterized by its unique way of oxygen supply. By using a U-shaped glass siphon outlet for effluent drainage, a continuous feeding and periodical draining process (feeding-draining process) could be accomplished in TBMES. During the feeding-draining process, the packed CAC biocathode could contact with air intermittently, which enabled it to entrap air bubbles with the rising of liquid level in the cathode chamber. Therefore, an intermittent aerobic/anoxic condition could be achieved in cathode chamber, which was suitable for the occurrence of simultaneous nitrification and denitrification process. Since the liquid level of cathode rose and fell regularly during the feeding-draining process, which was similar to the process of ocean tide, the biocathode was named as “tide-type biocathode”.

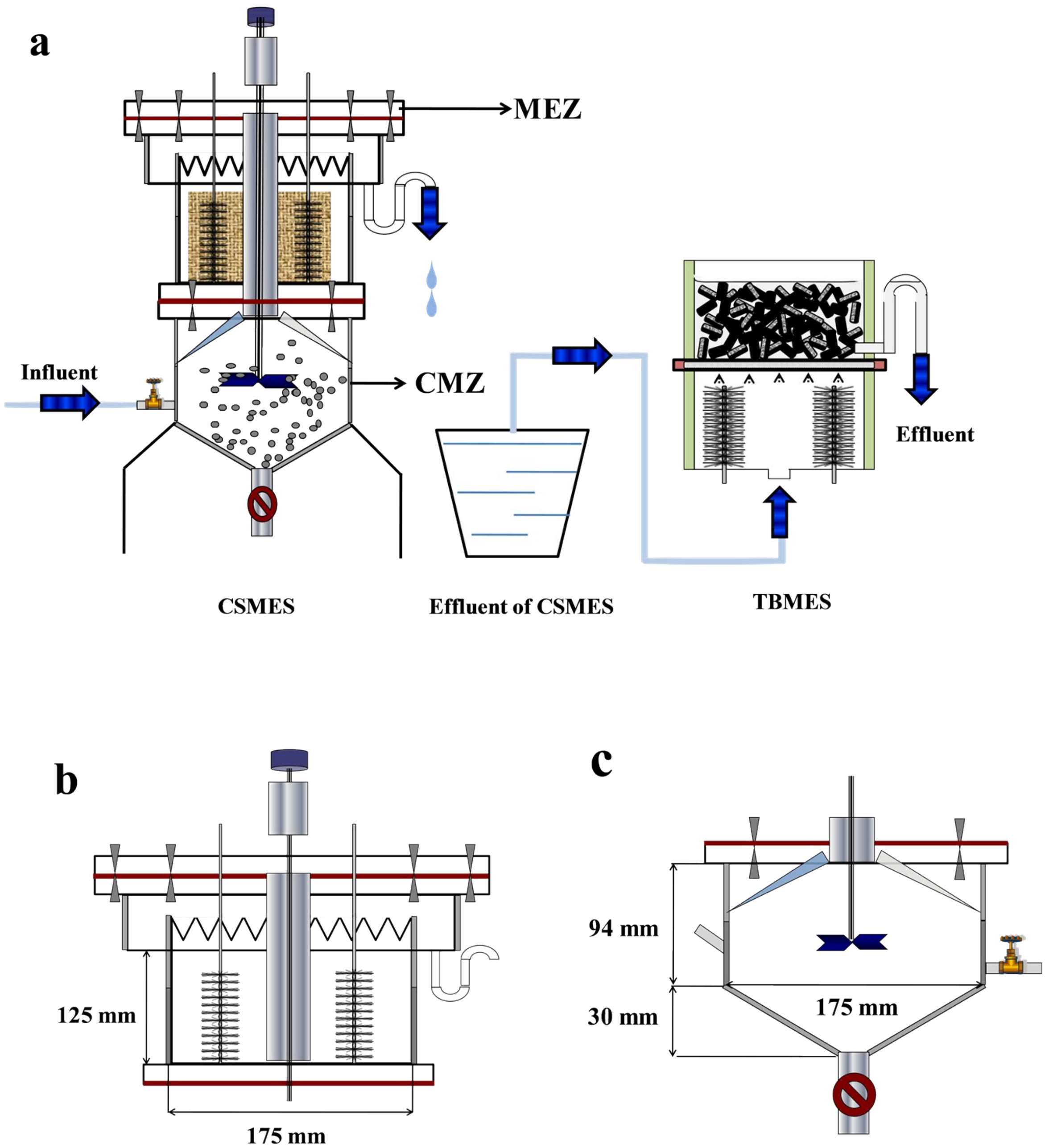
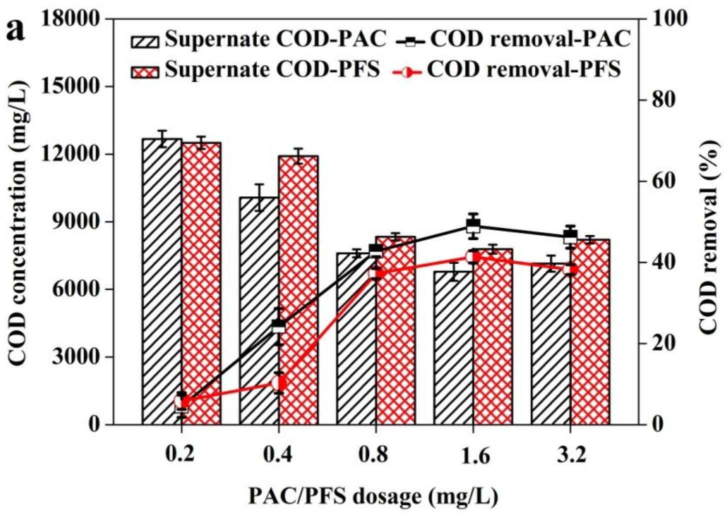


Fig. S1 (a) Schematic diagram of the CSMES-TBMES system (b) Microbial electrochemical zone, MEZ (c) Complete mixing zone, CMZ



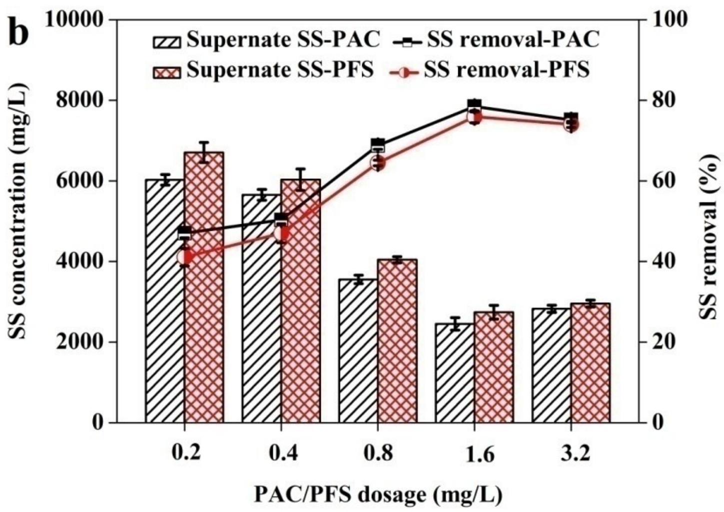
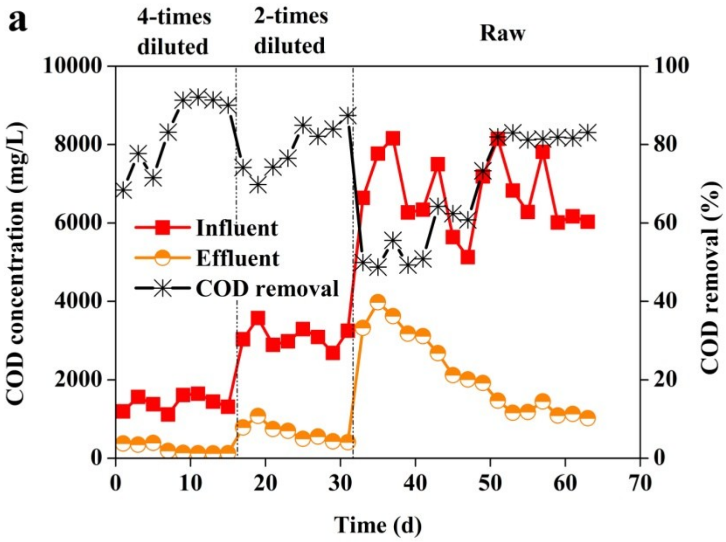


Fig. S2 Effects of PAC and PFS addition on removal of (a) COD and (b) SS at various concentrations (PAC: polyaluminium chloride; PFS: polyferric sulphate)



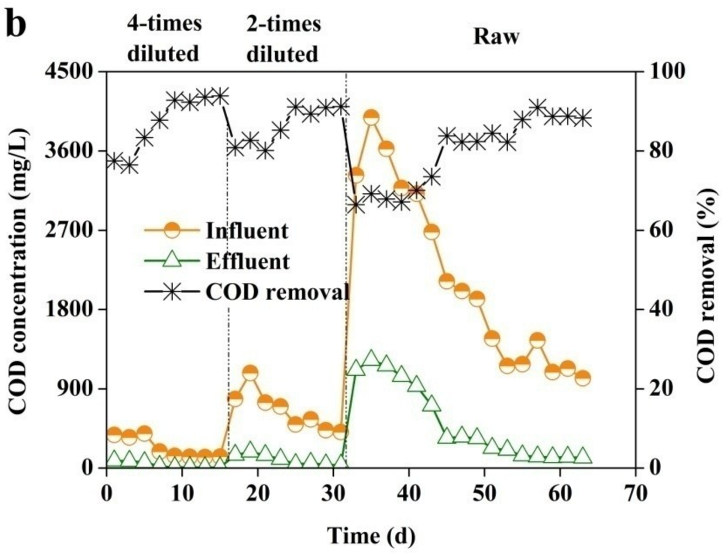


Fig. S3 Variation of COD concentrations and COD removal of (a) CSMES and (b) TBMES treating swine wastewater in the three-operation phase

The ammonia toxicity experiment for CSMES was operated at a fixed COD concentration of 6000 mg L^{-1} (using sucrose as the carbon source) in continuous flow mode (HRT = 12 h), with the TAN (total ammonia nitrogen) concentration varied from 300 to 1200 mg L^{-1} and increased in a stepwise manner. The system was operated for at least 15 days at each TAN concentration. Current generation of CSMES at different TAN concentrations was shown in Fig. S4.

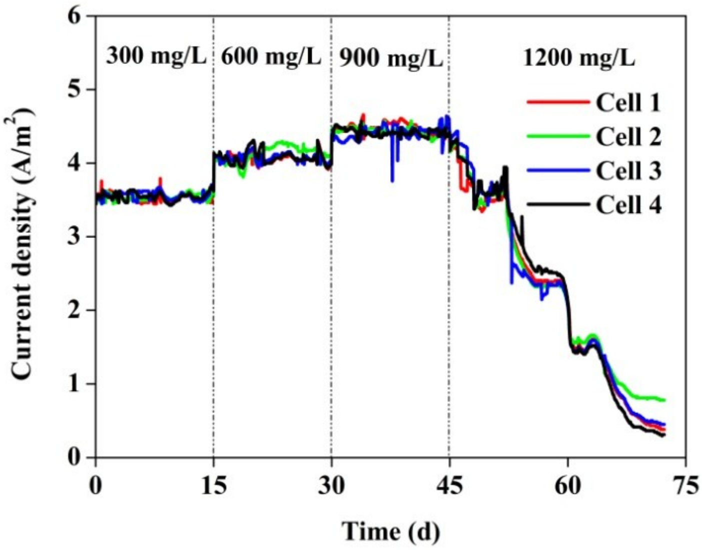


Fig.S4 Current generation of CSMES at different TAN concentrations (TAN: total ammonia nitrogen)

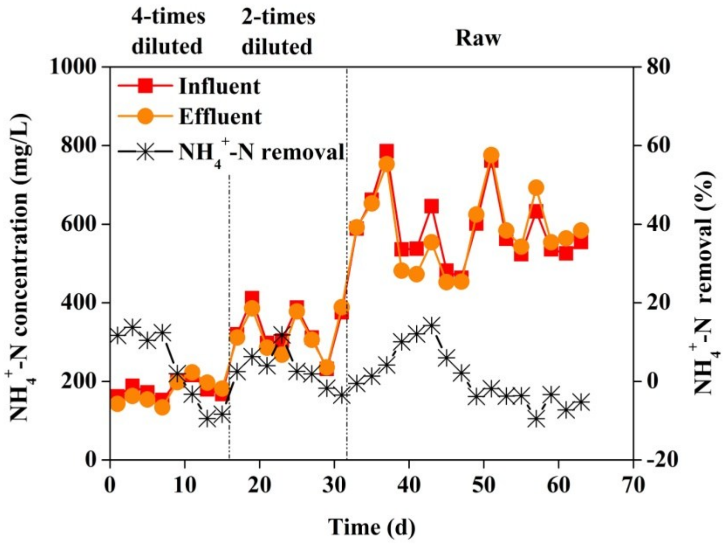


Fig. S5 Variation of total ammonium nitrogen concentrations and ammonium nitrogen removal of CSMES treating swine wastewater in the three-operation phase

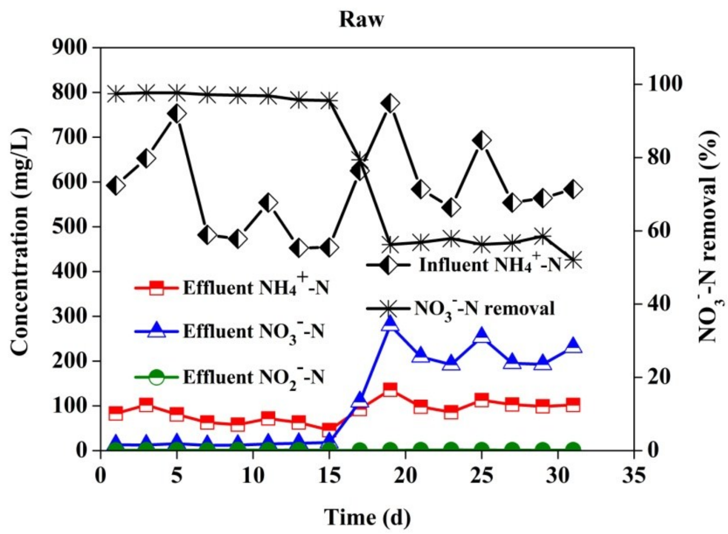


Fig. S6 Variation of NH_4^+-N, NO_3^--N and NO_2^--N concentrations as well as NO_3^--N removal of TBMES treating the effluent of CSMES in Phase III

Mass balance calculation

(1) COD in the influent of CSMES

$COD_{CSMES\text{-}Inf}=COD_{CSMES}\times Q_{CSMES}\times t=6745\ mg\ L^{-1}\times 0.17\ L\ h^{-1}\times 24\ h=27591.6\ mg\cdot d^{-1}$

(2) COD removal in the CSMES

$COD_{CSMES\text{-}Re}=(COD_{in}\text{-}COD_{out})\times Q_{CSMES}\times t=(6745\text{-}1207) mgL^{-1}\times 0.17Lh^{-1}\times 24h=22595.1mg\cdot d^{-1}$

(3) COD consumed for electricity generation in the CSMES

$COD_{CSMES\text{-}Ele}= COD_{CSMES\text{-}Re}\times CE=22595.1\ mg\cdot d^{-1}\times 0.6\%= 135.6\ mg\cdot d^{-1}$

(4) COD in the influent of TBMES

$COD_{TBMES\text{-}Inf}=COD_{TBMES}\times Q_{TBMES}\times t=1207\ mg\ L^{-1}\times 0.0084\ L\ h^{-1}\times 24\ h=243.3\ mg\cdot d^{-1}$

(5) COD removal in the TBMES

$COD_{TBMES\text{-}Re}=(COD_{in}\text{-}COD_{out})\times Q_{TBMES}\times t=(1207\text{-}128)\ mgL^{-1}\times 0.0084\ L\ h^{-1}\times 24\ h=217.5\ mg\cdot d^{-1}$

(6) COD consumed for electricity generation in the TBMES

$COD_{TBMES\text{-}Ele}= COD_{TBMES\text{-}Re}\times CE=217.5\ mg\cdot d^{-1}\times 34.2\%= 74.3\ mg\cdot d^{-1}$

Estimation of energy production and consumption

1. Electrical energy production of CSMES and TBMES

$$EP_{\mathrm{Electric}} = \frac{4I^{2}RT}{1000V}$$ * MERGEFORMAT (1)

$$EP_{\mathrm{CH_4}} = \frac{Y_{\mathrm{CH_4}} q_{\mathrm{CH_4}} T \eta_{\mathrm{CH_4}}}{24 \times 3600V}$$ * MERGEFORMAT (2)

$$EP_{\mathrm{CSMES}} = EP_{\mathrm{Electric}} + EP_{\mathrm{CH_4}}$$ * MERGEFORMAT (3)

$$EP_{\mathrm{TBMES}} = \frac{I^{2}RT}{1000V}$$ * MERGEFORMAT (4)

EP_{Clectric}—— Electrical energy production by the CSMES based on the average current output, kWh m^{-3};

EP_{CH4}——Electrical energy converted from the energy produced by methane combustion;

EP_{TBMES}——Electrical energy production by the TBMES based on the average current output, kWh m^{-3};

I —— Average current output in stable operation period of Phase III, 0.015 ± 0.001 A for the CSMES, 0.022 ± 0.018 A for the TBMES;

R ——External resistance, 10 Ω for the CSMES, 5 Ω for the TBMES;

T ——Hydraulic retention time, 24 h for the CSMES, 48 h for the TBMES;

V ——Working volume, 4×10^{-3} m^3 for the CSMES, 3.9×10^{-4} m^3 for the TBMES;

Y_{CH4}—— Methane combustion, 35.8 kJ L^{-1} CH_4;

η_{CH4}——Conversion efficiency of methane to electricity, 33%.

2. Energy consumption of TBMES

$$EC_{\mathrm{TBMES}} = \frac{gQE}{\eta_{\mathrm{pump}}} \cdot \frac{T}{V}$$

* MERGEFORMAT (5)

EC_{TBMES}——Energy consumption of TBMES treating 1 m^3 of pretreated swine wastewater, kWh m^{-3};

g —— 9.8 N kg^{-1};

Q —— flow rate of the feeding-draining process, 2.6 $\times 10^{-7}$ m^3 s^{-1};

E ——hydraulic pressure head, 0.07 m;

η_{pump}——energy conversation efficiency of the pump, 64 %[1]

Table S1 Detail costs of the components composed the CSMES-TBMES system

Cost analysis	Manufacturer Info	Unite price	Dosage[e]		Cost ($)	
			CSMES	TBMES	CSMES	TBMES
Carbon fiber brush	Toray, 12K carbon fiber	1.5 $ cm^{-1}	120 cm	15 cm	180	22.5
ACAC [a]	Nankai University	60 $ m^{-2} [d]	0.03 m^2	—	1.8	—
CAC [b]	Beijing Sanye Carbon Co. Ltd.	0.5 $ kg^{-1}	—	0.35 kg	—	0.175
Stainless steel mesh	Hebei Enfu Stainless Steel Mesh Co.	2.5 $ m^{-2}	—	0.01 m^2	—	0.025
PTFE	Shanghai Hesen Electric Co. Ltd.	67 $ L^{-1}	—	0.098 L	—	6.5
Glass fiber separator		8 $ m^{-2}	—	0.18 m^2	—	1.4
Reactor	Harbin Hongda Perspex Factory	230/30 $	1	1	230	30
Others [c]		50/7.5$			50	7.5
Total					461.8	66.7

a: ACAC: rolling activated carbon-PTFE air-cathode

b: CAC: columnar activated carbon

c: The item “other” mainly includes the cost of DI water, screws, glue, necessary tools etc.

d: The cost of ACAC was calculated to be 30 ~ 60 $ m^{-2}, 60 $ m^{-2} was chosen in this calculation

e: The dosage is based on the use for CSMES or TBMES

References

1 Y. Dong, Y. Feng, Y. Qu, Y. Du, X. Zhou and J. Liu, A combined system of microbial fuel cell and intermittently aerated biological filter for energy self-sufficient wastewater treatment, *Sci. Rep.*, 2015, **5**, 18070.