Direct medium-chain carboxylic-acid oil separation from a bioreactor by an electrodialysis/phase separation cell

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HIGHLIGHTS:

- Investigated the many different configurations to extract MCCAs by electrochemical separation technology
- Invented an electrodialysis/phase separation cell (ED/PS) that can separate a MCCA oil directly when coupled to a fermenter without pertraction
- Obtained a lower electric-power consumption of 1.05 kWh kg^{-1} MCCA oil by ED/PS with pertraction when compared to membrane electrolysis

BACKGROUND: Medium-chain carboxylic acids (MCCAs) are valuable platform chemicals with numerous industrial-scale applications. These MCCAs can be produced from waste biomass sources or syngas fermentation effluent through an anaerobic fermentation process called chain elongation. We have previously demonstrated successful approaches to separate >90%-purity oil with several MCCAs by integrating the anaerobic bioprocess with membrane-based liquid-liquid extraction (pertraction) and membrane electrolysis.[1] However, membrane electrolysis without pertraction was not able to separate MCCA oil.

RESULTS & DISCUSSION: First, we tested an ED/PS cell, which, when evaluated in series with pertraction, achieved a maximum MCCA-oil flux of 1,665 g d^{-1} per projected area (m^2) (19.3 mL oil d^{-1}) and a MCCA-oil transfer efficiency [100%*moles MCCA-oil moles $electrons^{-1}$] of 74% at 15 A m^{-2}. This extraction system demonstrated a ~10 times lower electric-power consumption of 1.05 kWh kg^{-1} MCCA oil when compared to membrane electrolysis in series with pertration (11.1 kWh kg^{-1} MCCA oil) at 15 A m^{-2}. Second, we evaluated our ED/PS as a stand-alone unit when integrated with the anaerobic bioprocess (without pertraction), and demonstrated, for the first time, that we can selectively extract and separate MCCA oil directly from chain-elongating bioreactor broth with just an abiotic electrochemical cell. We assumed that such a stand-alone unit would reduce capital and operating costs, but electric-power consumption increase considerably due to the lower MCCA concentrations in the bioreactor broth compared to the pertraction broth. Only a full techno-economic analysis will be able to determine whether the use of the ED/PS cell should be as a stand-alone unit or after pertraction.

CONCLUSION: It is envisaged that our ED/PS cell can be expanded to extract and separate other carboxylic acids from low-concentration solutions. However, the electric-power consumption increased considerably when the ED/PS cell extracted and phase separated the low carboxylic acid concentrations from the bioreactor broth compared to the high carboxylic concentrations from the pertraction solution.

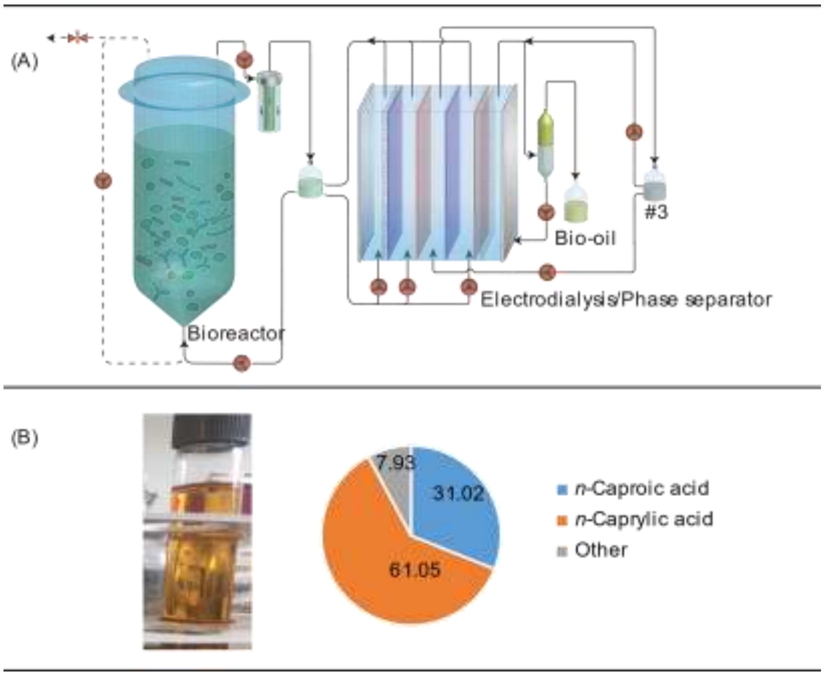

Figure 1. MCCA oil extraction directly from bioreactor broth. (A) Schematic of MCCA extraction using an ED/PS cell. (B) The purity of the MCCA oil product that was separated by ED/PS cell directly combined with a fermenter. The percentage of carboxylic acids in the separated oil is shown by the pie figure. The concentration of acetic acid (Ac) and *n*-butyric acid (Bu) was lower than the GC detection limit (Ac< 0.2 mM; <1.38%, Bu< 0.14 mM; <1.41%). The other compounds in the MCCA oil may be water, salts, and unknown compounds.

REFERENCES

1. Xu, J.; Guzman, J. J. L.; Andersen, S. J.; Rabaey, K.; Angenent, L. T., In-line and selective phase separation of medium-chain carboxylic acids using membrane electrolysis. Chem Commun 2015, 51, (31), 6847-6850.