Integrating electrochemical, biological, physical, and thermochemical process units to expand the applicability of anaerobic digestion

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1. Introduction

Anaerobic digestion (AD) is a well-established resource recovery technology that is technically feasible for a wide-range of applications. However, due to limited economic return from conventional by-products: biogas, heat, and electricity; many AD applications are not economical.

Here, we discuss several technology integrations that can be used to expand the product spectrum from AD (Figure 1) and provide additional options to generate revenue.

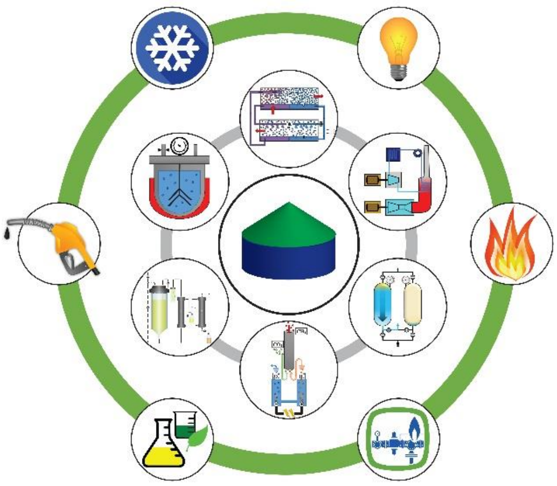

Figure 1. Product spectrum diagram with anaerobic digestion as the core process [1].

In the subsequent sections, we will provide a brief description and discuss the main advantages of four potential AD process integrations: 1) biogas upgrading; 2) power-to-gas (P2G) reforming; 3) process heat recovery for cooling; and 4) hydrothermal liquefaction (HTL) for bio-crude oil production.

2. Biogas Upgrading: Excluding CO_2

The goal of biogas upgrading is to enrich the methane content in biogas by removing CO_2 and other impurities. The product of biogas upgrading is often referred to as 'biomethane.' Several approaches for biogas upgrading exist, including: water scrubbing, amine scrubbing, membrane separation, pressure-swing adsorption, and cryogenic separation. Biogas upgrading is advantageous compared to conventional combined heat and power (CHP) production because it: 1) creates energy dense fuel; 2) permits injection into the natural gas (NG) grid; 3) can be used as a vehicle fuel (compressed or liquid NG); and 4) is easily stored and transported. The process heat from CHP, which represents more than half of the recovered energy, cannot be easily stored or transported, thus, is less versatile than biomethane.

3. P2G: Biomethane Using CO_2

P2G is another type of biogas upgrading technology, which uses the CO_2 in biogas along with H_2 (*e.g.*, from electrolysis), to generate additional methane *via* hydrogenotrophic methanogenesis. Biogas can be used directly, or CO_2 can be first separated then fed as a more purified stream. P2G is advantageous because it provides: 1) additional carbon recovery from CO_2; and 2) chemical storage for surplus renewable electric power (*e.g.,* from wind or solar). In P2G, CO_2 is treated as a commodity, and therefore also creates a market for industrial entities needing to dispose of CO_2 or seeking carbon credits.

4. Cooling Power from Process Heat

Electricity-driven refrigeration systems have dominated the market for the last several decades due to the low cost of electricity. However, in response to increasing electricity prices, absorption refrigeration (ABR) is making a comeback. ABR is a mature technology that uses low-quality heat (*e.g.,* hot water or combustion gas) rather than electricity to drive the refrigeration cycle. These systems become competitive when heating costs are < 1/5th the cost of electricity. ABR can be integrated with AD by using the process heat from CHP or methane directly. Cooling power is an important utility for many industrial processes and may be a more appropriate end-use for biogas.

5. HTL for Bio-Crude Oil Production

Hydrothermal liquefaction is a thermochemical process that utilizes the water already present in wet waste streams as the reaction medium. The wet feedstock (*e.g.,* food waste, AD effluent) is heated and pressurized to a temperature and pressure near the critical point of water (T_C=374°C; P_C=22 MPa). Under these conditions, organic components are rapidly hydrolysed then undergo various chemical reactions (*e.g.,* decarboxylation, dehydration) to form bio-crude oil at yields as high as 40-60% (*w/w*) [2]. Also, most of the remaining carbon is captured as dissolved carbon in the aqueous phase, thus, can be used by AD for additional energy recovery (Figure 2).

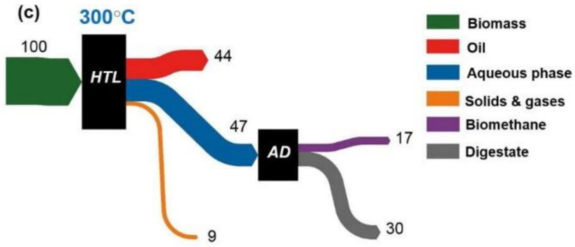

Figure 2. Product distribution for an integrated HTL – AD process. Values represent the chemical oxygen demand distribution following HTL at 300°C for 20 minutes *[2]*.

HTL can also follow AD to treat digestate, which could be particularly advantageous for recovering additional carbon/energy from biologically recalcitrant feedstocks such as lignocellulose. By providing bio-crude oil – a liquid fuel precursor – HTL further diversifies the product spectrum from AD.

6. Outlook

AD is outgrowing its origins as a mere heat and electricity production technology. Additional energy carriers and bio-products can now be exploited to help AD become more profitable and reach new industrial applications. Here, we highlight the value of biomethane, CO_2, cooling, and bio-oil in the new AD economy.

7. References

[1] L. T. Angenent et al. (2018). Integrating electrochemical, biological, physical, and thermochemical process units to expand the applicability of anaerobic digestion. Bio. Tech., Vol. 247, pp. 1085-1094.

[2] R. Posmanik et al. (2017). Coupling hydrothermal liquefaction and anaerobic digestion for energy valorization from model biomass feedstocks. Bio. Tech., Vol. 233, pp. 134-143.