Advanced Manure Treatment

Part 4: Energy extraction

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Directly combusting dried manure as an energy source has been used throughout history. Controlled anaerobic digestion has been used to biologically convert volatile solids in manure to methane (CH_4) for at least a century. The biogas produced can then be used as a fuel. Both of these methods are considered primary forms of manure treatment for energy extraction. Three additional advanced manure treatments for energy extraction are: Gasification, Pyrolysis, and Hydrothermal Liquefaction. They are compared with combustion in Table 1.

Gasification

Combustion produces only heat which is most commonly used for cooking or in modern equipment to heat water to produce steam which drives a turbine to generate electricity. Gasification, however, produces both heat and a combustible gas. Combustion occurs in an environment with sufficient oxygen. The gasification process, however, takes place with very little, or even no, oxygen.

The combustible gas produced is either a low energy "producer gas" or a medium energy "synthetic gas" or "syngas" comprised largely of carbon monoxide and hydrogen. If compressed air is used in the reaction, producer gas is the result because the components are diluted with nitrogen. If pure oxygen or steam in an anaerobic environment is used, syngas is produced.

Producer gas is sufficient for use in turbines, generators, fuel cells, furnaces, and boilers, or even co-fired with natural gas. However, the purer syngas is required for chemical reactions such as the production of gasoline, diesel, hydrogen, ethanol, or ammonia. Even the by-products of syngas production; oils, ash, and char; can be used as precursors for the production of filtration media, soil amendments, or cement additives.

Gasification can also be part of a highly efficient process for generating electricity called an Integrated Gasification Combined Cycle or IGCC. Here the syngas is burned in a turbine to generate electricity, then the waste heat from the turbine and the gasifier is recovered in a boiler and used to power a steam turbine to generate more electricity. If the low-pressure steam from the steam turbine is also recovered, efficiencies of 60% to 90% are possible. Unfortunately, these systems are only cost effective at larger scales due to the high capital investment required for the various components.

Pyrolysis

Pyrolysis is another promising, but less mature, thermal conversion technology that is often confused with gasification. While gasification occurs with little oxygen, pyrolysis proceeds with no oxygen.

Here the biomass substrate is heated to drive off moisture and various volatile organic compounds (VOCs). These are then condensed into a dark brown, low viscosity, high tar content liquid called bio-oil. This water-soluble material may be burned in a boiler, refined into other fuels for reciprocating engines and turbines, or as a component of other chemical reactions.

The bio-oil is more energy dense than syngas, but its corrosiveness may make long term storage problematic.

Biochar is a secondary product of gasification and pyrolysis. Unfortunately, as produced, the char may contain significant quantities of impurities that requires some refining. Biochar characteristics depend on the type of manure (or other input) and the specific time, temperature, pressure and anaerobic environment of the process. Once refined it can be used as a soil amendment, a precursor for activated charcoal, as a solid fuel that may be recycled directly back to the gasifying chamber or redirected elsewhere, or as a reductant in steel manufacturing where it improves the quality of steel while also reducing SO_x, N_xO, and other GHGs.

Hydrothermal liquefaction (HTL)

Gasification and pyrolysis are inefficient thermochemical reactions when the feedstock is too wet. They need a drier material to proceed in an energy efficient manner. HTL utilizes the enhanced reaction and solvation properties of water at higher temperatures (~350°C) and pressures (~2850 psi). At these elevated conditions, the more resistant components of manure, cellulose and lignin, are hydrolyzed into glucose and phenols, respectively. Further dehydration yields hydrogen and methane, and a liquid mixture of organic acids, ketones, and phenols called biocrude oil. This biocrude oil, in turn, can be further refined into biofuels.

Lower reaction temperatures (<250°C) favor the production of a solid carbonaceous material called HTC (hydrothermal conversion) coal. HTC coal has an energy density (28 MJ/kg) only slightly less than anthracite coal (33 MJ/kg), but HTC coal also has promising properties for use in supercapacitors or as anode and cathode materials for batteries and fuel cells used in the wind and solar power industries.

Overall power conversion efficiencies of HTL processes can reach upwards of 90% with a return on energy investment (energy out/energy in) of 140% to 250%.

Considerations

These advanced manure treatment energy extraction systems require sophisticated management and equipment for control and heat recovery. The high capital costs may preclude all but the largest farms from utilizing them at this time. The energy products may need specialized equipment for full utilization.

Table 1. Comparison of various energy extraction processes.

	Combustion	Gasification	Pyrolysis	Hydrothermal Liquefaction
Aim of Process	Produce high temp. flue gases – CO_2, H_20 – for heating	Produce high heating value gases – CO, H_2, methane	Thermal decomposition of waste to gases and condensed phases	Hydrolysis of cellulose and lignin from wet feedstock
Reaction Environment	Oxidizing – Excess O_2 available for reaction	Reducing – Low O_2	No Oxygen	Aqueous, No O_2, except incidental from steam
Reactant Gas	Air	Air, O_2, or steam	None	None
Temperature	850° to 1,200°C	500° to 1,500°C	500° to 800°C	300° to 400°C
Pressure	Atmospheric	Atmospheric	Slight positive	2175 to 2900 psi
Products	CO_2, H_20	CO, H_2, CO_2, H_2O, CH_4,	CO, H_2, CH_4, misc. hydrocarbons	H_2, CH_4, Producer Gas, BioCrude, HTC coal
By-Products	SO_2, NO_x, HCl, ash	H_2S, HCl, HCN, tar, NH_3, ash, biochar	H_2S, HCl, HCN, tar, NH_3, ash, biochar	High Chemical Oxygen Demand effluent

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