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(54) **Title**: TWO STAGE PYROLYSIS OF ORGANIC WASTE

(57) **Abstract**: Organic waste is treated by pyrolysis or by anaerobic digestion followed by pyrolysis of the digestate. The pyrolysis is performed in two staged reactors. The second stage reactor treats char produced in the first stage. The temperature of the first stage reactor is preferably 450 degrees C or less. The temperature of the second stage reactor is higher than the temperature of the first stage, for example by 50 degrees C or more. Optionally, there may be a char cooler, a water sprayer, or both downstream of the char outlet of the second reactor. In an exemplary system, a digestate outlet is connected to the inlet of the first pyrolysis reactor. A pyrolysis liquid outlet of the first pyrolysis reactor is connected to the digester. Char produced in the second pyrolysis reactor may be used as a soil amendment.

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TWO STAGE PYROLYSIS OF ORGANIC WASTE

FIELD

[0001] This specification relates to treating organic waste and pyrolysis.

BACKGROUND

[0002] US Patent 8,877,468 describes a process in which materials containing lignocellulose are treated by pyrolysis under conditions (low temperature and long residence time) that favour the production of a liquid containing organic acids and alcohols. This liquid is suitable for conversion to biogas (primarily methane) in an anaerobic digester. US Patent 8,877,468 is incorporated herein by reference.

INTRODUCTION

[0003] Organic waste can include, for example, the organic fraction of municipal waste, yard waste, industrial or commercial waste, agricultural waste or wastewater treatment primary or secondary sludge. Organic waste may be treated by pyrolysis or, preferably, by anaerobic digestion followed by pyrolysis of the digestate.

[0004] In a process described herein, pyrolysis is performed in two stages. The first stage treats a feedstock comprising organic waste to produce permanent gas, liquid (which may be condensed from vapor), and char. The second stage treats the char produced in the first stage. At least some of the first stage char (which may include oil in the pores of the first stage char) is converted into a gas in the second stage. The temperature of the first stage is preferably 450 degrees C or less. The temperature of the second stage is higher than the temperature of the first stage, for example by 50 degrees C or more.

[0005] An apparatus described herein has two pyrolysis reactors. A char outlet from the first reactor is connected to a feed inlet of the second reactor. Optionally, there may be a char cooler, a water sprayer, or both downstream of the char outlet of the second reactor.

[0006] A system described herein comprises the two-stage pyrolysis apparatus coupled to an anaerobic digester. A digestate outlet is connected to the inlet of the first reactor. A pyrolysis liquid outlet of the first reactor is connected to the digester.

[0007] In the apparatus, system and process described above, the first stage pyrolysis temperature favors the production of an aqueous liquid with dissolved compounds over the production of pyrolysis oil. The aqueous liquid is readily digested in an anaerobic digester, whereas pyrolysis oil is frequently toxic or at least inhibits growth of microorganisms in a digester. However, the inventor has observed that pyrolysis under conditions that provide a digestible liquid produces oily char that is not very porous. Treatment in the second stage increases the quality of the char as a soil amendment. In at least some cases, the first stage char is converted from a waste product to a useful product.

BRIEF DESCRIPTION OF THE FIGURES

[0008] Figure 1 is a schematic drawing of an organic waste treatment system.

DETAILED DESCRIPTION

[0009] Figure 1 shows a system 10 for treating organic waste 12. Optionally, the organic waste 12 may be pre-treated. For example, the organic waste 12 may have been separated from other waste, for example in a press or by a screen. Additionally or alternatively, solid particles waste 12 may be homogenized or reduced in size.

[0010] The waste 12 is sent to an anaerobic digester 14, alternatively referred to as a digester for brevity. The digester 14 may have one or more mixed covered tanks. Suitable digesters are sold under the Triton and Helios trade marks by UTS Biogas or Anaergia. The digester 14 produces product biogas 16 which may, for example, be used to produce energy in a combined heat and power unit or upgraded to produce biomethane. The inside of the digester contains sludge 18. A stream of sludge 18, alternatively called digestate, is also withdrawn from the digester 14.

[0011] Sludge 18 is sent to a drying unit 20. In the drying unit 20, the sludge 18 is treated in a mechanical dewatering unit, for example a centrifuge, filter press or screw press. The mechanical dewatering unit separates the sludge 20 into a waste liquid, which may be sent to a sanitary drain or treated on site for discharge or re-use, and a de-watered cake. The de-watered cake is sent to a sludge cake dryer to further reduce its water content. Preferably, the de-watered cake is formed into digestate pellets, granules or flakes 22, depending on the type of dryer used. The pellets 22 may be transported, for example, by screw conveyors or in bags or bins.

[0012] Pellets 22 are sent to a first pyrolysis reactor 24. The first pyrolysis reactor 24 heats the pellets 22 in the absence or a deficiency of oxygen, to produce first biochar 26, pyrolysis liquid 28 and pyrolysis gas 30. The pyrolyzer produces gas that passes through a condenser. In the condenser two streams are formed: pyrolysis liquid 28 and noncondensable or permanent gas 30. Pyrolysis liquid 28, which may include condensable vapors, is recycled to anaerobic digester 14 as additional feedstock for digestion. Pyrolysis gas 30 is also sent back to the digester 14. The pyrolysis gas 30 may be injected into the bottom of the digester 14.

[0013] The pyrolysis gas 30 is scrubbed to some extent as it rises in bubbles though sludge 18 in the digester 14. The pyrolysis gas 30 later mixes with biogas 16 in the headspace of the digester 14 to increase its heat value. Part of the pyrolysis gas 30, particularly the hydrogen, may also be transferred into the sludge 18 and be biologically converted to methane. The transfer of pyrolysis gas 30 to sludge 18 in the digester 14 can optionally be enhanced by injecting the pyrolysis gas 62 as fine bubbles, by adding the pyrolysis gas through a dissolution cone into a stream of recirculating sludge, or by recirculating the headspace gas. Optionally, if the recycle of pyrolysis gas 30 increases the concentration of carbon monoxide (CO) in the biogas 16 too much, CO can be removed from the pyrolysis gas 30 or biogas 16 by membrane separation, or the pyrolysis gas 30 can be at least partially converted to methane before being added to the digester 14.

[0014] The temperature in the first pyrolysis reactor 24 may be over 270 degrees C., preferably over 300 degrees C, more preferably over 320 degrees C, but less than 450 degrees C, preferably less than 400 degrees C and more preferably less than 350 degrees C. The residence time may be 5-30 minutes, but preferably 10-20 minutes. Pyrolysis of organic, for example cellulosic, material at over 450 degrees C produces an excess of oils that may be toxic to microorganisms in an anaerobic digester. Pyrolysis at lower temperatures produces even less of the toxic substances and also produces more pyrolysis liquid 28 relative to pyrolysis gas 30. This is beneficial since the pyrolysis liquid 28 is easily mixed into sludge 18 in the anaerobic digester 14 and enhances production of biogas 16. However, at very low temperatures the production of biochar 26 dominates. A temperature of 320 to 350 degrees and residence time of about 10-20 minutes is particularly useful.

[0015] The first biochar 26 is conveyed, for example dropped, into a second pyrolysis reactor 32. The first biochar 26 is preferably not cooled before second stage pyrolysis. Second pyrolysis reactor 32 operates at a higher temperature. Temperature in the second pyrolysis reactor 32 may be 50 degree C or more higher than the temperature in the first pyrolysis reactor 24. The temperature in the second pyrolysis reactor 32 may be over 400 degrees C., preferably over 450 degrees C. The temperature in the second pyrolysis reactor 32 may be 550 degrees C or less, preferably 500 degrees C or less. The residence time may be 5-30 minutes, but preferably 10-20 minutes. For example, the second pyrolysis reactor 32 may treat the first char 26 at 450-500 degrees C for 10-20 minutes.

[0016] The second pyrolysis reactor 32 produces second pyrolysis gas 34. Second pyrolysis gas 34 may be returned to digester 14 as described for the pyrolysis gas 30. The second pyrolysis reactor 32 might also produce a small amount of liquid. If so, this pyrolysis liquid tends to contain oils that are toxic to the microorganisms in the digester 14. The second pyrolysis liquid can be recycled through the second pyrolysis reactor until it is converted into gas, disposed of, or sold for use as pyrolysis oil.

[0017] The second pyrolysis reactor 32 also produces second char 36. Second char 36 passes through a cooler 38 to produce cooled char 40. The cooler 38 may be, for example, a jacketed screw cooler with cool water flowing through a hollow screw to provide indirect cooling. Cooled char 40 passes under a water sprayer 42 to produce stabilized char 44. If not sprayed, the cooled char 40 absorbs water from the air and reheat. The amount of water required to stabilize the char (i.e. reduce its tendency to re-heat) appears to be related to the relative humidity of the ambient air. Second char 36, or preferably cooled char 40 or stabilized char 44, may be used as a soil enhancer.

[0018] In an example, primary and secondary sludge from a wastewater treatment plant was fed to an anaerobic digester 14. The digestate 18 was dried (92% solids) and pelletized and sent to a first pyrolysis reactor 24. The mass of first char 26 was 55% of the mass of pellets 22 on a dried solids basis. Thus the first pyrolysis reactor 24 reduced the volume of sludge 18 solids for disposal by 45%. However, the first char 26 was not acceptable for use a soil amendment. Its porosity and adsorption were low, possibly because there was pyrolysis oil in the pores of the first char 26. The first char 26 smelled like oil.

[0019] The first char 26 emerged from the first pyrolysis reactor 24 as a charcoal-like pellet that could be conveyed to a second pyrolysis reactor 32 while still hot, along with some ash. The first char 26 was re-pyrolyzed in a second pyrolysis reactor at 450 degrees C. The second char 36 was reduced in mass (relative to first char 26) by another 5-10% of the dried solids mass of pellets 22. Second char 36 was cooled and sprayed with water to 96% solids. The second char was porous and high in nitrogen and phosphorous (11%).

CLAIMS:

I claim:

1. A process for treating organic waste comprising steps of,
pyrolysing the organic waste in a first stage and producing at least a first char; and,
pyrolysing the first char in a second stage and producing a second char.

2. The process of claim 1 wherein the temperature in the second stage is higher than the temperature of the first stage, for example by 50 degrees C or more.

3. The process of claim 1 or 2 wherein the temperature of the first stage is 450 degrees C or less

4. The process of any of claims 1 to 3 wherein the first stage produces a liquid and the further comprises treating the liquid in an anaerobic digester.

5. The process of any of claims 1 to 4 wherein the organic waste comprises digestate.

6. The process of any of claims 1 to 5 further comprising cooling the second char.

7. The process of any of claims 1 to 6 further comprising spraying water on the second char.

8. The process of any of claims 1 to 7 further comprising adding gas produced in the first stage or the second stage or both to sludge in an anaerobic digester.

9. The process of any of claims 1 to 8 wherein the first stage pyrolysis is conducted at a residence time of 5 to 30 minutes.

10. A pyrolysis apparatus comprising,
a first pyrolyis reactor having a char outlet; and,
a second pyrolysis reactor having in inlet,

wherein the char outlet form the first reactor is connected to the feed inlet of the second reactor.

11. The apparatus of claim 10 further comprising a char cooler downstream of a char outlet of the second reactor.

12. The apparatus of claim 10 or 11 having a water sprayer downstream of the char outlet of the second reactor.

13. The apparatus of any of claims 10 to 12 further comprising an anaerobic digester.

14. The apparatus of claim 13 wherein a digestate outlet of the anaerobic digester is connected to the inlet of the first reactor.

15. The apparatus of claim 13 or 14 wherein a pyrolysis liquid outlet of the first reactor is connected to the digester.

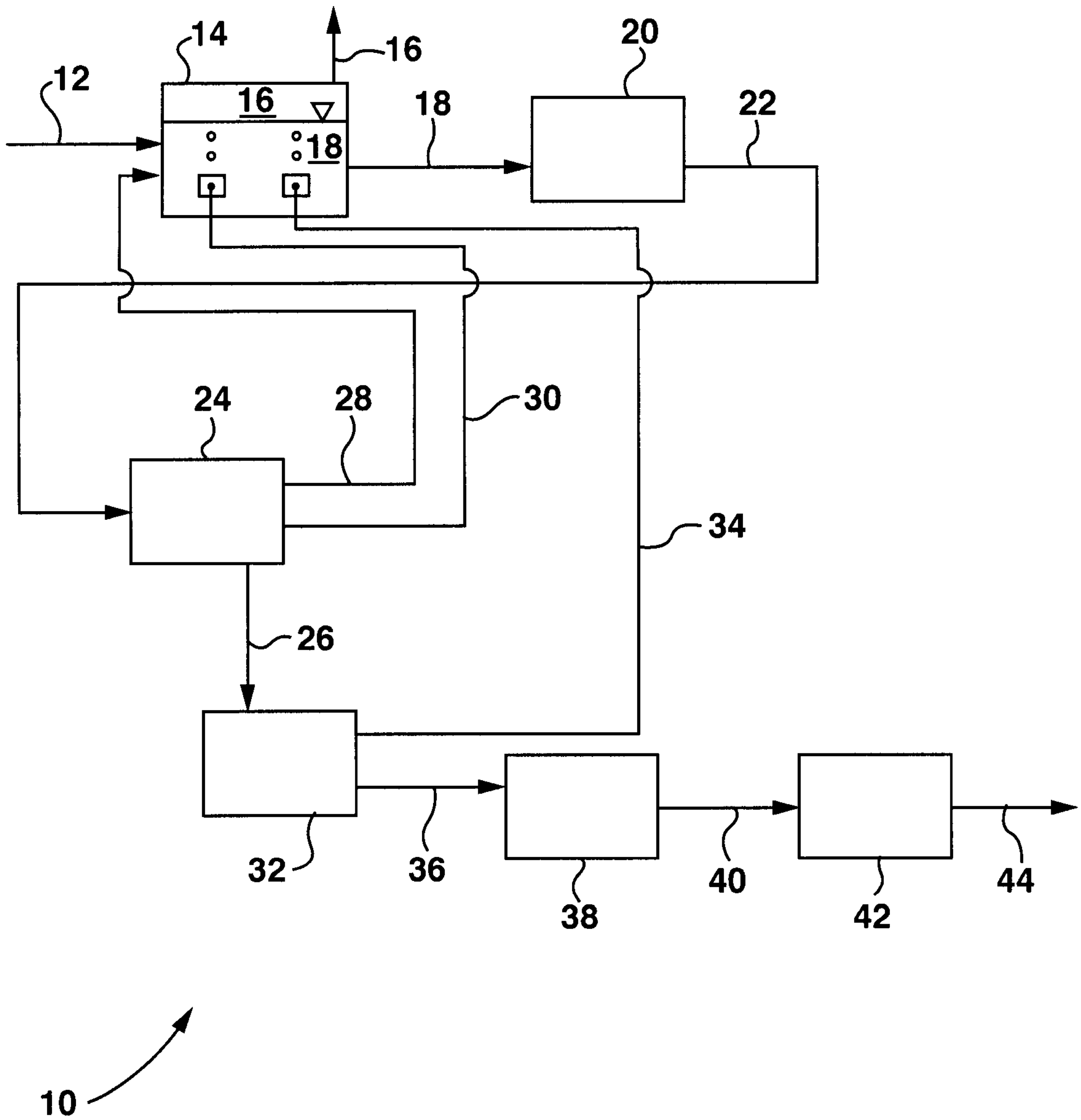

FIG. 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2017/050335

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***A62D 3/35*** (2007.01) , ***B09B 3/00*** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: A62D 3/35 (2007.01) , B09B 3/00 (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Documents cited in any documents listed in section C below, and in the present Description.

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Canadian Patents Database; INTELLECT; Questel Orbit; Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	McKendry P. Energy production from biomass (part 3): gasification technologies. Bioresource technology. 2002 May 31;83(1):55-63, [online] [retrieved on 12 June 2017 (12-06-2017)]. Retrieved from the Internet: https://eclass.duth.gr/modules/document/file.php/	1 – 15
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A	A.V.BRIDGEWATER, D. MEIER, D.RADLEIN, "An overview of fast pyrolysis of biomass". Organic Geochemistry, 1999, Vol. 30, pp. 1479 - 1493, [online] [retrieved on 12 June 2017 (12-06-2017)]. Retrieved from the Internet: <https://www.researchgate.net/profile/Dietrich_Meier/publication/222485410_An_Overview_of_Fast_Pyrolysis_of_Biomass/links/02bfe512926de56965000000.pdf	1 - 15

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

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