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(54) **VOLATILIZATION AND OXIDATION OF ORGANIC WASTE**

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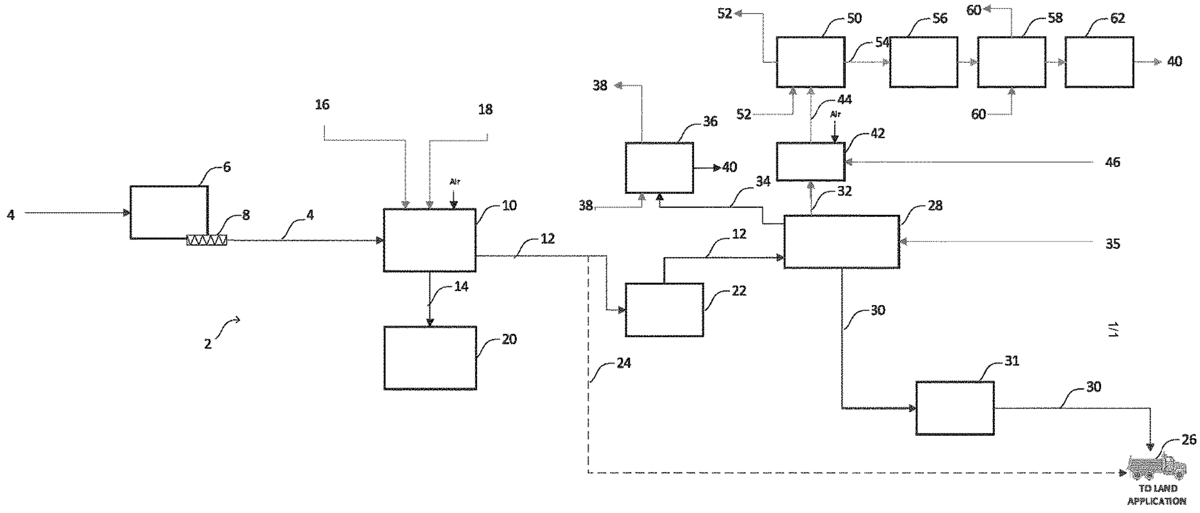
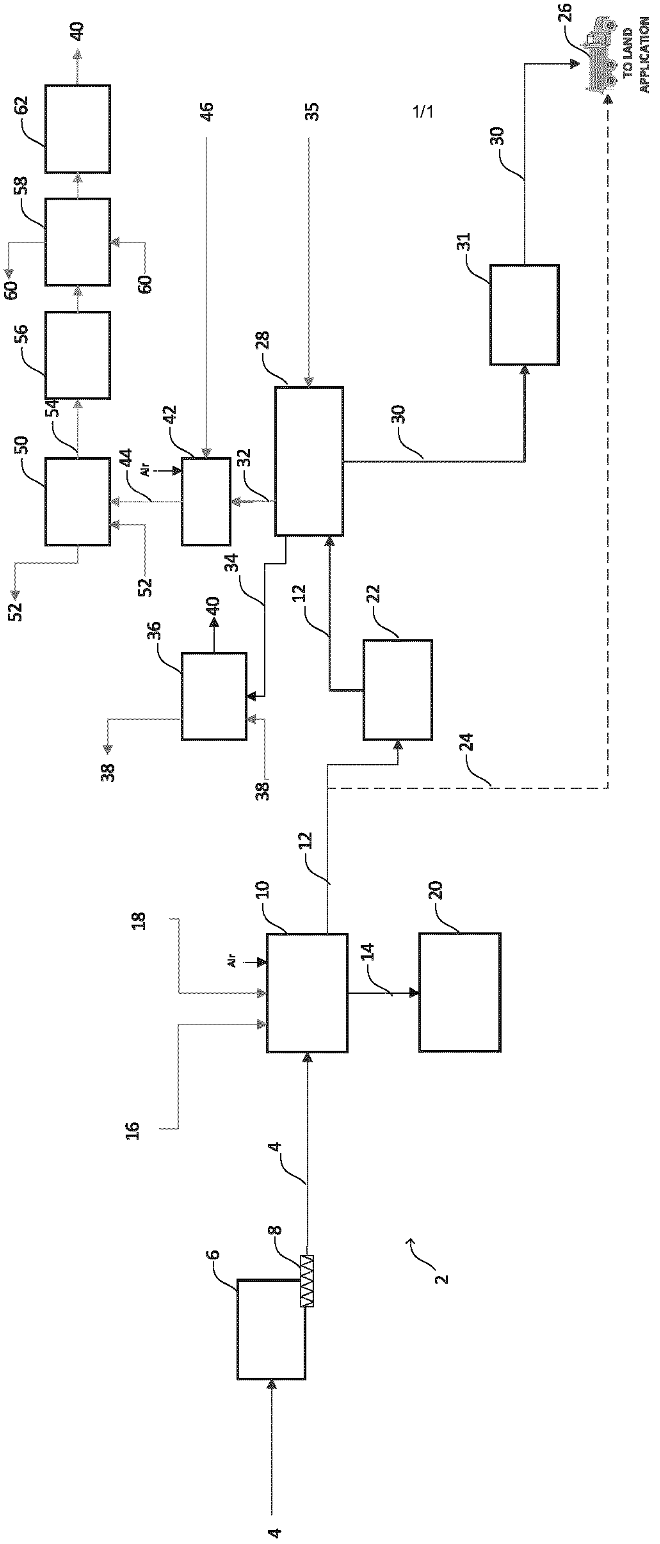
(57) ABSTRACT

In a system and process, organic waste is treated in a reactor to volatilize contaminants such as Perfluoroalkyl substances (PFAS) compounds and/or Contaminants of Emerging Concern (CECs) from the organic waste. Biochar may have reduced or undetectable PFAS compounds or CECs. Most or all of the gas may be thermally oxidized to convert PFAS compounds and/or CECs into less harmful and/or less toxic products or elemental compounds, which may be further removed. Energy may be recovered from one or more parts of the herein described system and process.

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VOLATILIZATION AND OXIDATION OF ORGANIC WASTE

FIELD

[0001] The present disclosure relates to treating organic waste using a volatilization process and oxidation.

BACKGROUND

[0002] The following paragraphs are not an admission that anything discussed in them is prior art or part of the knowledge of persons skilled in the art.

[0003] Perfluoroalkyl substances (PFAS) are synthetic organofluorine chemical compounds that have fluorine atoms attached to an alkyl chain, which include well-known Perfluorooctanesulfonic acid (PFOS) and Perfluorooctanoic acid (PFOA). PFOS and PFOA are persistent organic pollutants that have been detected in humans and wildlife and are detrimental to health because of bioaccumulation in tissues. PFAS compounds play an economic role in industry due to their use in emulsion polymerization to produce fluoropolymers, and they are found in products such as stain repellents, polishes, paints, and coatings. PFAS compounds have chemical structures comprising carbonfluorine (C—F) bonds, among the strongest covalent bonds in nature, and therefore are resistant to degradation. PFAS are water-soluble and have been found in surface water, ground water, drinking water sources, wastewater treatment plant discharges and biosolids, and landfills.

[0004] Contaminants of emerging concern (CECs) are artificial organic substances that are introduced in the environment due to industrialization and manmade activity, and may cause damage to the ecosystem and human health problems. CECs include pharmaceuticals and personal care products, organic wastewater compounds, antimicrobials, antibiotics, animal and human hormones, as well as domestic and industrial detergents. Examples of CECs include ibuprofen, bisphenol A (BPA), flurosemide, naproxen, and estrogen. CECs released during their use or disposal of products containing the CECs, have been found in surface water, ground water, drinking water sources, wastewater treatment plant discharges and biosolids, and landfills. CECs also include Polychlorinated Biphenyls (PCBs), which are a group of man-made organic chemicals consisting of carbon, hydrogen and chlorine atoms. PCBs may have a detrimental effect on human health and the environment. CECs also include Polycyclic Aromatic Hydrocarbons (PAHs), which are hydrocarbons that are composed of multiple aromatic rings that occur naturally in coal, crude oil, and gasoline. PAHs are produced when coal, oil, gas, wood, garbage, and tobacco are burned. PAHs have been found in water sources and may have a detrimental effect on human health and the environment.

[0005] Due to the health and environmental concerns of PFAS and other contaminants, such as CECs, municipalities are regulating and/or may regulate the amount of PFAS and other contaminants, such as CECs, found in organic waste treatment discharges, such as wastewater treatment plant discharges.

INTRODUCTION

[0006] The following introduction is intended to introduce the reader to this specification but not to define any of them.

[0007] Organic waste can include, for example, wastewater treatment primary or secondary sludge, biosolids, source separated organics (SSO), food waste, or the organic fraction of municipal solid waste, yard waste, industrial or commercial waste, or agricultural waste.

[0008] Organic waste may be treated by a volatilization process to extract the energy content of the organic waste. Examples of volatilization processes include pyrolysis and gasification. Pyrolysis differs from gasification in that pyrolysis is performed in the absence of oxygen whereas gasification is performed in an environment containing oxygen. Pyrolysis of organic waste produces syngas (i.e. pyrolysis gas), liquid (which may be condensed from vapor), and biochar by heating organic waste in the absence of oxygen. Pyrolysis liquid can be used as an industrial fuel to generate heat and electrical power and can be updated into transportation fuels and specialty chemicals. Syngas can be recycled into a pyrolysis process to provide process heat and supplemental fuel. Biochar produced by pyrolysis of organic waste can be used as an agricultural soil enhancement. The relative yield of products from pyrolysis may vary with temperature, for example, temperatures of 400-500 degrees C. may produce more biochar, while higher temperatures, for example up to and above 700 degrees C., may favor the yield of liquid and gaseous fuel components. In one or more known pyrolysis processes, pyrolysis liquid and/or syngas produced from pyrolysing organic waste is fed to an anaerobic digester to be used as additional feedstock for digestion and/or is used as fuel. Gasification of organic waste produces syngas, liquid (which may be condensed from vapor), and char. Similar to the above-described uses of pyrolysis products, gasification products may be used as fuel and/or soil enhancement.

[0009] The inventors have observed that, through the collection of wastewater and solid waste, the organic fractions of solid waste or biosolids contain PFAS compounds and/or other contaminants, such as CECs, at detectable levels that have known undesirable environmental impacts and/or unknown environmental impacts. Moreover, the inventors have observed that pyrolysis or gasification of organic waste under conditions that favor the extraction of energy from the organic waste and/or that favor energy recovery from the pyrolysis or gasification reaction, produced biochar or char containing PFAS compounds and/or other contaminants, such as CECs, that are higher than acceptable levels, such as levels set by local municipalities. The inventors have discovered that treating organic waste under pyrolysis or gasification conditions that favor the volatilization of at least a portion of organic waste, for example, the volatilization of most or all PFAS compounds and/or CECs, and subsequently thermally oxidizing the syngas, allows for 1) the conversion of PFAS compounds and/or CECs present in the organic waste into products that are less harmful, less toxic, and/or are valuable; and 2) energy recovery. For example, the herein described pyrolysis or gasification conditions allow for a biochar or char to be produced with: decreased concentration levels of PFAS compounds and/or CECs, concentration levels of PFAS compounds and/or CECs at below detection limits, and/or concentration levels of PFAS compounds and/or CECs below levels set by local municipalities. The herein described thermal oxidizing conditions of the syngas allow for conversion of the PFAS compounds and/or CECs into less toxic and/or less harmful compounds, such as less toxic and/or less harmful gases, which may be subsequently removed producing a flue gas with: decreased concentration levels of PFAS compounds and/or CECs, concentration levels of PFAS compounds and/or CECs at below detection limits, and/or concentration levels of PFAS compounds and/or CECs below levels set by local municipalities. The herein described process conditions of thermally oxidizing syngas produced from the volatilization of organic waste allow for energy recovery at one or more parts of the process.

[0010] In a process described herein, feedstock comprising organic waste is pyrolysed or gasified and one or more products of the pyrolysis or gasification are oxidized. The temperature of the pyrolysis or gasification may be from about 300 to about 850 degrees C. The residence time of the pyrolysis or gasification may be from about 10 to about 90 minutes. PFAS compounds and/or CECs from the organic waste may be volatilized producing a biochar or char that has a decreased PFAS compound and/or CECs content. Most or all of the syngas is oxidized to produce at least flue gas. The temperature of thermal oxidation may be from about 700 to about 1350 degrees C. The residence time of thermal oxidation may be from about 0.1 to about 10.0 seconds. PFAS compounds and/or CECs from the syngas may be converted into less harmful and/or less toxic gases, and subsequently removed from the gas, for example, by conversion into salt. Optionally, the flue gas is treated to remove additional contaminants, for example, NOx and/or SOx. Optionally, the flue gas may be used to provide energy, for example heat, for pyrolysis or gasification, and/or for drying feedstock.

[0011] An apparatus described herein has a volatilization reactor and a thermal oxidizer. The volatilization reactor may be a pyrolysis reactor or a gasification reactor. A volatilization reactor outlet is connected to an inlet of the thermal oxidizer. Optionally, the thermal oxidizer receives at least some or all the gas from the volatilization reactor. Optionally, the apparatus comprises a gas treatment unit for treating flue gas from the thermal oxidizer, for example, a NOx and/or a SOx treatment unit. Optionally, the apparatus comprises one or more heat exchangers in communication with the thermal oxidizer used to provide heat for the volatilization reactor and/or for a dryer for drying feedstock. Optionally, a heat exchanger may be included between a NOx treatment unit and a SOx treatment unit for additional heat recovery.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The FIGURE is a schematic drawing of an organic waste treatment system.

DETAILED DESCRIPTION

[0013] The FIGURE shows an example of a system **2** for treating organic waste. The system **2** may be used, for example, to treat biosolids **4** from a municipal wastewater treatment plant (WWTP) (not shown). Optionally, the biosolids **4** may be pre-treated. For example, the biosolids **4** may have been separated from other waste, for example in a press or by a screen. Additionally or alternatively, the biosolids **4** may be dewatered to a high solids content, for example, about 25% TS or more, and sent to a dryer **10**. Optionally, the dewatered biosolids may be stored in a dewatered biosolids storage unit **6** before being sent to a dryer **10** by, for example, a screw conveyor **8**. The dryer **10** produces a dried biosolids **12** and exhaust **14**. The dried biosolids **12** may have a high solids content, for example, about 90% TS, and an energy content of from about 6,500 to about 9,000 BTU/lb dry matter (DM). In some jurisdictions, some or all of the dried biosolids **12** may be a class A biosolid **24**, or similarly designated biosolid **24**, which may be separated and hauled offsite **26**. The dryer **10** is in communication with a pyrolysis reactor **28** to send some or all of the dried biosolids **12** to pyrolysis reactor **28**, for example, dryer **10** is connected directly or indirectly to pyrolysis reactor **28** by connector pipes that provide passage for dried biosolids **12**. Alternatively, the dryer **10** is in communication with a gasification reactor (not shown) to send some or all of the dried biosolids **12** to the gasification reactor. The exhaust **14** may be sent to a scrubber **20**, for example, a three-stage wet scrubber, to remove contaminants to meet local emissions standards. The dryer **10** may require heat, for example 20 MMBTU/hr or more, which may be provided by natural gas **16** and heat **18** recovered from the herein described system. Optionally, the dried biosolids **12** are stored in dried biosolid storage unit **22** before being sent to pyrolysis reactor **28**.

[0014] The system **2** includes pyrolysis reactor **28** with an inlet to receive biosolids **4**. Alternatively, the system includes a gasification reactor (not shown) with an inlet to receive biosolids **4**. Preferably, the pyrolysis reactor **28** is a one-stage high temperature pyrolysis reactor powered by natural gas **35**, which provides heat, for example, from about 7 to about 10 MMBTU/hr. The pyrolysis reactor **28** heats the biosolids **4** in the absence or a deficiency of oxygen, to produce biochar **30**, and syngas **32**. The temperature of the pyrolysis reactor **28** may be from about 300 to about 850 degrees C., for example, about 300 degrees C.; about 350 degrees C.; about 400 degrees C.; about 450 degrees C.; about 500 degrees C.; about 550 degrees C.; about 600 degrees C.; about 650 degrees C.; about 700 degrees C.; about 750 degrees C.; about 800 degrees C.; about 850 degrees C.; or from any temperature listed above to any other temperature listed above. The residence time may be from about 10 to about 90 minutes, for example, about 10 minutes; about 20 minutes; about 30 minutes; about 40 minutes; about 50 minutes; about 60 minutes; about 70 minutes; about 80 minutes; about 90 minutes; or from any time listed above to any other time listed above. In an alternative system comprising a gasification reactor, the temperature and residence time of the gasification reactor is the same as the herein disclosed temperature and residence time of the pyrolysis reactor **28**.

[0015] Pyrolysis or gasification of organic waste, for example biosolids **4**, at about 300 degrees C. or above and at a residence time of 10 minutes or more, volatilizes at least a portion of the organic waste **4**, for example, most or all Perfluoroalkyl substances (PFAS) compounds and/or Contaminants of Emerging Concern (CECs) in the organic waste **4**. This is beneficial since the produced biochar **30** or char has a reduced content of PFAS compounds and/or CECs compared to biochar or char produced in one or more known processes operating under pyrolysis or gasification conditions that favor the extraction of energy from the organic waste and/or that favor energy recovery from the pyrolysis or gasification reaction. In some examples, the biochar **30** or char has an PFAS content that meets the requirements of municipalities, such as a content level below about 6 ng/g, below about 4 ng/g, below about 3 ng/g, below about 2 ng/g, or below detection limits, or below about 2.5 ppb (PFOA) and/or below 5.2 ppb (PFOS). Fast pyrolysis, for example having a residence time of seconds, and much less than 10 minutes, may not provide sufficient thermal heat transfer to volatize most or all of the PFAS compounds and/or CECs in the organic waste **4**. Optionally, the biochar **30** or char may be used as a soil enhancer typically after being collected and stored in a char storage unit **31**, and then hauled off site **26**. The biochar **30** or char may have an energy content, for example, of about 4700 BTU/lb DM.

[0016] Optionally, burner exhaust **34** from the pyrolysis reactor **28** or a gasification reactor is sent to a heat exchanger **36** to produce recovered heat **38** and cooled exhaust **40**. The pyrolysis reactor **28** may be in thermal communication with heat exchanger **37**, for example, by being directly or indirectly connected to heat exchanger **37** by connector pipes that provide passage for burner exhaust. The recovered heat **38** may be used to heat air for dryer **10**, for example, by heating fluid such as air, water, or thermal oil that is sent to the dryer **10**. The heat exchanger **38** may be in thermal communication with dryer **10**, for example, by being directly or indirectly connected to dryer **10** by connector pipes providing passage for heated fluid. The recovered heat **38** may provide energy to the dryer **10**, for example, from about 1 to about 3 MMBTU/hr.

[0017] Most or all of the syngas **32** or the pyrolysis or gasification products excluding the biochar **30** or char, is sent to a thermal oxidizer **42** having an inlet to receive the syngas **32**. The thermal oxidizer **42** heats and oxidizes the syngas **32** to produce oxidizer exhaust (or flue gas) **44** comprising carbon dioxide, water vapor, and hydrogen fluoride. In some examples, the oxidizer exhaust **44** may also comprise oxidized sulfur compounds, oxidized nitrogenous compounds, and/or oxidized chlorinated compounds. Optionally, the thermal oxidizer is supplemented by natural gas **46**, which provides additional heat for destruction of flue gas, for example, from about 2 to about 6 MMBTU/hr. The temperature of the thermal oxidizer **42** may be from about 700 to about 1350 degrees C., for example, from about 850 to about 1250 degrees C.; about 700 degrees C.; about 750 degrees C.; about 800 degrees C.; about 850 degrees C.; about 900 degrees C.; about 950 degrees C.; about 1000 degrees C.; about 1050 degrees C.; about 1100 degrees C.; about 1150 degrees C.; about 1200 degrees C.; about 1250 degrees C.; about 1300 degrees C.; about 1350 degrees C.; or from any temperature listed above to any other temperature listed above. The residence time may be from about 0.1 to about 10.0 seconds, for example, from about 5.0 to about 10 seconds; from about 0.1 to about 4.0 seconds; about 0.1 seconds; about 0.5 seconds; about 1.0 seconds; about 1.5 seconds; about 2.0 seconds; about 2.5 seconds; about 3.0 seconds; about 3.5 seconds; about 4.0 seconds; about 4.5 seconds; about 5.0 seconds; about 5.5 seconds; about 6.0 seconds; about 6.5 seconds; about 7.0 seconds; about 7.5 seconds; about 8.0 seconds; about 8.5 seconds; about 9.0 seconds; about 9.5 seconds; about 10.0 seconds; or from any time listed above to any other time listed above. Residence times more than about 10.0 seconds may be undesirable, for example, because the flowrate may create oxidation stages that are too large for economic purchase. Commercial thermal oxidizer units are available, for example, oxidizers capable of producing low NOx flue gas. The thermal oxidizer **42** may be a 3-stage low NOx thermal oxidizer. The first stage of the 3-stage oxidizer is performed at a high temperature, for example, from about 1093 to about 1315 degrees C., or about 1232 degrees C., and sub-stoichiometric air to dissociate nitrogen in the syngas **32** to N_2. The second stage is a quench stage. The third stage is a re-oxidation stage with excess oxygen for complete combustion and destruction of the syngas **32**. The 3-stage low NOx thermal oxidizer can reach temperatures of from about 850 to about 982 degrees C. The 3-stage low NOx thermal oxidizer may be preferably, for example when producing low NOx flue gas that can be handled with a post thermal oxidizer selective catalytic reduction (SCR) to remove NOx to limits acceptable for flue gas discharge, is desirable. Using burners other than those herein described to clean syngas in its gaseous state may be more expensive and less efficient.

[0018] The herein described thermal oxidization of syngas **32** converts most or all of the PFAS compounds and/or CECs into less harmful and/or less toxic compounds, such as gases, which may be further converted into corresponding salts. For example, under the herein described thermal oxidation conditions, PFAS compounds may be converted into hydrogen fluoride (HF), which may be converted into hydrofluoric acid with the addition of water. The flue gas may be fed to a SOx scrubber, which uses a caustic scrubber (for example, NaOH or potassium hydroxide). The fluoride ions in the water may react with Na+ or K+ ions and form sodium fluoride salt or potassium fluoride salt. This is beneficial since the resulting flue gas, and subsequently produced salt, is less harmful and/or less toxic than PFAS compounds and/or CECs, and may be removed from the oxidizer exhaust **44** resulting in an exhaust that may meet required municipality levels of fluorine compounds and/or CECs. Sending most or all of the syngas **32**, or the pyrolysis or gasification products excluding the biochar **30** or char, to a thermal oxidizer **42** for removing or destroying PFAS compounds and/or CECs may be more energy efficient than one or more known processes that remove PFAS compounds and/or CECs from organic waste because in the herein described process, the biochar **30** or char contains little to no PFAS compounds and/or CECs and therefore does not require further treatment to remove PFAS compounds and/or CECs.

[0019] Optionally, the oxidizer exhaust **44** from the thermal oxidizer **42** is sent to a heat exchanger **50** to produce recovered heat **52** and cooled oxidizer exhaust **54**. The thermal oxidizer **44** may be in thermal communication with heat exchanger **50**, for example, by being directly or indirectly connected to heat exchanger **50** by connector pipes that provide passage for oxidizer exhaust **44**. The recovered heat **52** may be used to heat air for dryer **10**, for example, by heating fluid such as air, water, or thermal oil that is sent to the dryer **10**. The heat exchanger **50** may be in thermal communication with dryer **10**, for example, by being directly or indirectly connected to dryer **10** by connector pipes providing passage for heated fluid. The recovered heat **52** may provide heat to the dryer **10**, for example, from about 12 to about 30 MMBTU/hr. In some examples, the oxidizer gas **44** is sent to heat exchanger **37**, which is in thermal communication with pyrolysis reactor **28** or alternatively, a gasification reactor. Sending most or all of the syngas **32**, or the pyrolysis or gasification products excluding the biochar **30** or char, to a thermal oxidizer **42** and recovering energy from the oxidizer exhaust **44** may be beneficial over processes that recover energy from the syngas **32** because more energy may be recovered from the higher temperature oxidizer exhaust **44** compared to the lower temperature syngas **32**. Moreover, the process of heating syngas **32** subsequent to pyrolysis or gasification and extracting energy from the oxidizer exhaust **44** may be a more efficient energy recovery process than recovering energy from the syngas subsequent to pyrolysis or gasification and then heating the cooled syngas **32** during thermal oxidation before extracting additional energy from the oxidizer exhaust **42**.

[0020] Optionally, the oxidizer exhaust **44** may be passed in counterflow with the biosolids in a double wall (tube within furnace) pyrolysis reactor **28** or alternatively, a gasification reactor, to supply heat indirectly for pyrolysis or gasification, for example, without the flue gas contacting the biosolids.

[0021] Optionally, the oxidizer exhaust **44** may be treated in one or more gas treatment units, for example, a NOx gas treatment unit **56** and a SOx gas treatment unit **62**, to meet local emission requirements. The thermal oxidizer **42** may be in communication with the one or more gas treatment units, for example, by being directly or indirectly connected to the one or more gas treatment units by connector pipes that provide passage for oxidizer exhaust **44**. The NOx gas treatment unit **56** may comprise selective catalytic reduction (SCR) technology, and the SOx gas treatment unit **62** may comprise a caustic scrubber. Blow down from the wet caustic scrubber may contain sodium fluoride, sodium sulfite and sodium bisulphate, and can be sent to a WWTP (not shown). Optionally, exhaust from the NOx treatment unit **56** may be sent to a heat exchanger **58** to produce received heat **60** and cooled NOx treated exhaust. The exhaust from the NOx treatment unit **56** may be in thermal communication with heat exchanger **58**, for example, by being directly or indirectly connected to heat exchanger **58** by connector pipes that provide passage for NOx treatment unit exhaust. The recovered heat **60** may be used to heat air for dryer **10**, for example, by heating air, water, or thermal oil that is sent to the dryer **10**. Optionally, oxidizer gas **44** is sent to heat exchanger **37**, which is in thermal communication with pyrolysis reactor **28** or alternatively, a gasification reactor. The recovered heat **52** may provide heat to the dryer **10**, for example, from about 0.5 to about 1.5 MMBTU/hr.

EXAMPLES

Example 1

[0022] In an example of a system **2** as described above, dewatered biosolids **4** from an anaerobic digestion system available from Anaergia under the OMNIVORE trademark, had a solids content of 25% TD, a VS/TS of 62% and an energy content of 6,940 BTU/lb DM. The dewatered biosolids **4** (71,900 gallons per day (GPD) or 299 short tonnes per day (TPD)) was sent to a 360 cubic yard cake storage unit **6**. Screw conveyor **8** was used to transfer the biosolids **4** from the storage unit **6** to dryer **10**, which had a drying capacity of 9 short tonnes per hour (TPH) and a heat demand of 30.4 MMBTU/hr. Natural gas provided 12.6 MMBTU/hr and recovered heat from the system **2**, as described below, provided 17.8 MMBTU/hr. The dryer **10** produced dried biosolids having a solids content of 90% TS, and dryer exhaust **14**, which was sent to a three-stage scrubber **20**.

[0023] The dried biosolids **12** (83 TPD) was sent to dried biosolids storage **22** before being sent to pyrolysis reactor **28**. The pyrolysis reactor **28** had a pyrolysis capacity of 3.5 TPH, and produced syngas **32**, biochar **30**, and burner exhaust **34**. Natural gas provided 8 MMBTU/hr of heat to the pyrolysis reactor **28**. Produced biochar **30** (37.5 TPD) had a solids content of 100% TS, an energy content of 4,782 BTU/lb DM, and a reduced content of PFAS compounds and/or CECs. The biochar **30** was stored in a 250 cubic yard storage unit **31**, and then hauled off site **26**.

[0024] The burner exhaust **34** was sent to heat exchanger **36**, which provided 2 MMBTU/hr of heat to air **38** from the dryer **10** that flowed through the heat exchanger **36** and returned to the dryer **10**. Cooled burner exhaust **40** was sent to a stack.

[0025] The syngas **32** was sent to thermal oxidizer **42**. The thermal oxidizer **42** produced oxidizer exhaust **44** comprising carbon dioxide, water vapor, and hydrogen fluoride. The oxidizer exhaust **44** was sent to heat exchanger **50**, which provided 15 MMBTU/hr of heat to oil **52** from the dryer **10** that flowed through the heat exchanger **50** and returned to the dryer **10**. Cooled oxidizer exhaust **54** was sent to a NOx treatment unit **56**. Following NOx treatment, the treated exhaust was sent to heat exchanger **58**, which provided 0.8 MMBTU/hr of heat to water **60** from the dryer **10** that flowed through the heat exchanger **58** and returned to the dryer **10**. Cooled treated exhaust was sent to SOx treatment unit **62**, and following treatment, the exhaust **40** was sent to a stack.

Example 2

[0026] In another example of a system **2** as described above, dewatered biosolids **4** from an anaerobic digester digestate that was hydrolyzed, had a solids content of 30% TD, a VS/TS of 60% and an energy content of 6,720 BTU/lb DM. The dewatered biosolids **4** (55,500 gallons per day (GPD) or 232 short tonnes per day (TPD)) was sent to a 360 cubic yard cake storage unit **6**. Screw conveyor **8** was used to transfer the biosolids **4** from the storage unit **6** to dryer **10**, which had a drying capacity of 6.4 short tonnes per hour (TPH) and a heat demand of 21.8 MMBTU/hr. Natural gas provided 6.6 MMBTU/hr and recovered heat from the system **2**, as described below, provided 15.2 MMBTU/hr. The dryer **10** produced dried biosolids having a solids content of 90% TS, and dryer exhaust **14**, which was sent to a three-stage scrubber **20**.

[0027] The dried biosolids **12** (77 TPD) was sent to dried biosolids storage **22** before being sent to pyrolysis reactor **28**. The pyrolysis reactor **28** had a pyrolysis capacity of 3.5 TPH, and produced syngas **32**, biochar **30**, and burner exhaust **34**. Natural gas provided 7.45 MMBTU/hr of heat to the pyrolysis reactor **28**. Produced biochar **30** (37.5 TPD) had a solids content of 100% TS, an energy content of 4,782 BTU/lb DM, and a reduced content of PFAS compounds and/or CECs. The biochar **30** was stored in a 250 cubic yard storage unit **31**, and then hauled off site **26**.

[0028] The burner exhaust **34** was sent to heat exchanger **36**, which provided 1.8 MMBTU/hr of heat to air **38** from the dryer **10** that flowed through the heat exchanger **36** and returned to the dryer **10**. Cooled burner exhaust **40** was sent to a stack.

[0029] The syngas **32** was sent to thermal oxidizer **42**. The thermal oxidizer **42** produced oxidizer exhaust **44** comprising carbon dioxide, water vapor, and hydrogen fluoride. The oxidizer exhaust **44** was sent to heat exchanger **50**, which provided 12.7 MMBTU/hr of heat to oil **52** from the dryer **10** that flowed through the heat exchanger **50** and returned to the dryer **10**. Cooled oxidizer exhaust **54** was sent to NOx treatment unit **56**. Following NOx treatment, the treated exhaust was sent to heat exchanger **58**, which provided 0.7 MMBTU/hr of heat to water **60** from the dryer **10** that flowed through the heat exchanger **58** and returned to the dryer **10**. Cooled treated exhaust was sent to SOx treatment unit **62**, and following treatment, the exhaust **40** was sent to a stack.

Example 3

[0030] In another example of a system **2** as described above, dewatered biosolids **4** from undigested sludge, had a solids content of 25% TD, a VS/TS of 80% and an energy content of 8,960 BTU/lb DM. The dewatered biosolids **4** (88,675 gallons per day (GPD) or 370 short tonnes per day (TPD)) was sent to a 360 cubic yard cake storage unit **6**. Screw conveyor **8** was used to transfer the biosolids **4** from the storage unit **6** to dryer **10**, which had a drying capacity of 11 short tonnes per hour (TPH) and a heat demand of 37.6 MMBTU/hr. Natural gas provided 4.5 MMBTU/hr and recovered heat from the system **2**, as described below, provided 33.1 MMBTU/hr. The dryer **10** produced dried biosolids having a solids content of 90% TS, and dryer exhaust **14**, which was sent to a three-stage scrubber **20**.

[0031] The dried biosolids **12** (103 TPD) was sent to dried biosolids storage **22** before being sent to pyrolysis reactor **28**. The pyrolysis reactor **28** had a pyrolysis capacity of 4.3 TPH, and produced syngas **32**, biochar **30**, and burner exhaust **34**. Natural gas provided 9.9 MMBTU/hr of heat to the pyrolysis reactor **28**. Produced biochar **30** (37.5 TPD) had a solids content of 100% TS, an energy content of 4,782 BTU/lb DM, and a reduced content of PFAS and/or CECs. The biochar **30** was stored in a 250 cubic yard storage unit **31**, and then hauled off site **26**.

[0032] The burner exhaust **34** was sent to heat exchanger **36**, which provided 2.5 MMBTU/hr of heat to air **38** from the dryer **10** that flowed through the heat exchanger **36** and returned to the dryer **10**. Cooled burner exhaust **40** was sent to a stack.

[0033] The syngas **32** was sent to thermal oxidizer **42**. The thermal oxidizer **42** produced oxidizer exhaust **44** comprising carbon dioxide, water vapor, and hydrogen fluoride. The oxidizer exhaust **44** was sent to heat exchanger **50**, which provided 29 MMBTU/hr of heat to oil **52** from the dryer **10** that flowed through the heat exchanger **50** and returned to the dryer **10**. Cooled oxidizer exhaust **54** was sent to NOx treatment unit **56**. Following NOx treatment, the treated exhaust was sent to heat exchanger **58**, which provided 1.5 MMBTU/hr of heat to water **60** from the dryer **10** that flowed through the heat exchanger **58** and returned to the dryer **10**. Cooled treated exhaust was sent to SOx treatment unit **62**, and following treatment, the exhaust **40** was sent to a stack.

Example 4

[0034] In another example of a system **2** as described above, dried biosolids **12** to be fed into pyrolysis reactor **28** having a solids content of 93% TS was compared to biochar **30** having a solids content of 99% TS produced by pyrolysis of dried biosolids **12**. The pyrolysis was conducted at a temperature of 510 degrees C. and a residence time of 30 minutes. The proximate analysis of the dried biosolids **12** and the biochar **30** are shown in Table 1. In Table 2, the nitrogen, phosphorus, potassium, and sulfur content of the dried biosolids **12** and the biochar **30** are compared. Tables 3 and 4 show a reduction of PFAS compounds in the biochar **30** compared to dried biosolids **12**. Table 5 shows a reduction of CECs in the biochar **30** compared to dried biosolids **12**.

TABLE 1

Proximate analysis for dried biosolids and pyrolysis biochar

Parameter	Unit	Wastewater Treatment Plant Dried Biosolids	Pyrolysis Biochar Product
Moisture	% dw[1]	7.2	0.25
Ash	% dw	27.6	65
Volatile Matter	% dw	61.8	33.9
Fixed Carbon	% dw	3.4	0.9
Heat Value	BTU/lb	6973	4969
pH	—	6.70	6.98

[1] % dw = % dry weight basis.

TABLE 2

N, P, K and S analysis for dried biosolids and pyrolysis biochar

Parameter	Detection Limit (% dw)	Wastewater Treatment Plant Dried Biosolids (% dw)	Pyrolysis Biochar Product (% dw)
Total Nitrogen (N)	0.01	5.89	1.85
Carbon Nitrogen Ratio (C/N)	—	6.1	21.1
Ammoniacal Nitrogen (N)	0.01	0.24	ND
Nitrate Nitrogen (N)	0.01	ND	ND
Total Phosphate (P_2O_5)	0.1	6.48	16.9
Potash (K_2O)	0.1	0.24	0.47
Soluble Potash (K_2O)	0.01	0.24	0.47
Sulfur	0.05	2.1	1.66

1. % dw = % dry weight basis.

TABLE 3

Per- and polyfluoroalkyl substances (PFAS) in dried biosolids and pyrolysis biochar

Analyte	CAS	Detection Limit (ng/g)	Wastewater Treatment Plant Dried Biosolids (ng/g)	Pyrolysis Biochar Product (ng/g)
PFBA	375-22-4	2.00	ND[1]	ND
PFPeA	2706-90-3	2.00	ND	ND
PFBS	375-73-5	2.00	ND	ND
4:2 FTS	757124-72-4	2.00	ND	ND
PFHxA	307-24-4	2.00	5.53	ND
PFPeS	2706-91-4	2.00	ND	ND
PFHpA	375-85-9	2.00	ND	ND
PFHxS	355-46-4	2.00	ND	ND
6:2 FTS	27619-97-2	2.00	ND	ND
PFOA	335-67-1	2.00	2.92	ND
PFHpS	375-92-8	2.00	ND	ND
PFNA	375-95-1	2.00	ND	ND
PFOSA	754-91-6	2.00	ND	ND
PFOS	1763-23-1	2.00	3.47	ND
PFDA	335-76-2	2.00	ND	ND
8:2 FTS	39108-34-4	2.00	ND	ND
MeFOSAA	2355-31-9	2.00	3.14	ND
EtFOSAA	2991-50-6	2.00	ND	ND
PFUnA	2058-94-8	2.00	ND	ND

TABLE 3-continued

Per- and polyfluoroalkyl substances (PFAS) in dried biosolids and pyrolysis biochar

Analyte	CAS	Detection Limit (ng/g)	Wastewater Treatment Plant Dried Biosolids (ng/g)	Pyrolysis Biochar Product (ng/g)
PFDS	335-77-3	2.00	ND	ND
PFDOA	307-55-1	2.00	ND	ND
PFTrDA	72629-94-8	2.00	ND	ND
PFTeDA	376-06-7	2.00	ND	ND

[1] ND = not detected, below detection limit. All results on a dry weight basis.

TABLE 4

Per- and polyfluoroalkyl substances (PFAS) in dried biosolids and pyrolysis biochar

Analyte	CAS	Detection Limit (ng/g)	Biosolid Pellets (ng/g)	Biochar 1000° F. 120 min[1] (ng/g)	Biochar 950° F. 30 min (ng/g)	Biochar 650° F. 30 min (ng/g)	Cake (ng/g)	Biochar 700° F. 30 min (ng/g)
PFBA	375-22-4	2.00	ND[2]	ND	ND	ND	3.80	ND
PFPeA	2706-90-3	2.00	ND	ND	ND	ND	2.59	ND
PFBS	375-73-5	2.00	ND	ND	ND	ND	3.88	3.14
4:2 FTS	757124-72-4	2.00	ND	ND	ND	ND	ND	ND
PFHxA	307-24-4	2.00	5.53	ND	ND	ND	7.62	ND
PFPeS	2706-91-4	2.00	ND	ND	ND	ND	ND	ND
PFHpA	375-85-9	2.00	ND	ND	ND	ND	ND	ND
PFHxS	355-46-4	2.00	ND	ND	ND	ND	ND	ND
6:2 FTS	27619-97-2	2.00	ND	ND	ND	ND	3.47	3.24
PFOA	335-67-1	2.00	2.92	ND	ND	ND	4.98	ND
PFHpS	375-92-8	2.00	ND	ND	ND	ND	ND	ND
PFNA	375-95-1	2.00	ND	ND	ND	ND	ND	ND
PFOSA	754-91-6	2.00	ND	ND	ND	ND	ND	ND
PFOS	1763-23-1	2.00	3.47	ND	ND	ND	10.20	12.60[3]
PFDA	335-76-2	2.00	ND	ND	ND	ND	2.64	ND
8:2 FTS	39108-34-4	2.00	ND	ND	ND	ND	2.09	2.08
MeFOSAA	2355-31-9	2.00	3.14	ND	ND	ND	2.52	3.77
EtFOSAA	2991-50-6	2.00	ND	ND	ND	ND	ND	2.01
PFUnA	2058-94-8	2.00	ND	ND	ND	ND	ND	ND
PFDS	335-77-3	2.00	ND	ND	ND	ND	ND	ND
PFDoA	307-55-1	2.00	ND	ND	ND	ND	ND	ND
PFTrDA	72629-94-8	2.00	ND	ND	ND	ND	ND	ND
PFTeDA	376-06-7	2.00	ND	ND	ND	ND	ND	ND

[1] 1000° F. refers to the pyrolysis temperature, and 120 min refers to the retention time.

[2] ND = not detected above detection limit.

[3] Higher concentrations in the biochar are the result of concentration of solids (e.g., 50% wt biochar yield) along with partial destruction.

TABLE 5

Contaminants of Emerging Concern (CECs) in dried biosolids and pyrolysis biochar

Analyte	Detection Limit (ng/g)	Wastewater Treatment Plant Dried Biosolids (ng/g)	Pyrolysis Biochar Product (ng/g)
2-hydroxy-ibuprofen	4.0	48.6	ND[1]
4-nonylphenol	900	164250	ND
Bisphenol A	6.0	1760	ND
Carbamazepine	0.02	24.0	ND
Estrogen	22.5	31.4	ND
Furosemide	4.0	9.4	ND
Gemfibrozil	0.8	35.0	ND
Glipizide	0.8	ND	ND
Glyburide	0.8	ND	ND

TABLE 5-continued

Contaminants of Emerging Concern (CECs) in dried biosolids and pyrolysis biochar

Analyte	Detection Limit (ng/g)	Wastewater Treatment Plant Dried Biosolids (ng/g)	Pyrolysis Biochar Product (ng/g)
Hydrochlorothiazide	8.5	11.6	ND
Ibuprofen	4.0	121	ND
Naproxen	2.0	25.5	ND
Sulfamethoxazole	0.03	0.3	ND
Triclocarban	0.4	207	ND
Triclosan	6.0	2310	ND

TABLE 5-continued

Contaminants of Emerging Concern (CECs) in dried biosolids and pyrolysis biochar

Analyte	Detection Limit (ng/g)	Wastewater Treatment Plant Dried Biosolids (ng/g)	Pyrolysis Biochar Product (ng/g)
Trimethoprim	0.02	2.6	ND
Warfarin	0.4	ND	ND

[1] ND = not detected. Below detection limit. All results on a dry weight basis.

Example 5

[0035] In another example of a system **2** as described above, the thermal oxidizing parameters are provided in Table 6.

TABLE 6

Thermal oxidizer parameters

Thermal Oxidizer	Dual-Stage Combustion
Operating Temperature	Stage 1 Outlet: 2,250° F. Stage 2 Outlet: 1,650° F. Heat Exchanger Outlet: 750° F.
Retention Time	>1 second (nominal)
Destruction Efficiency	>99% of VOC (or ≤20 ppm)
Combustion Blower 480 V/3 Ph/60 Hz TEFC	15 HP
Recycle Flue Gas Blower 480 V/3 Ph/60 Hz TEFC	150 HP (designed for 750° F.)
Specially Designed Process Burner - Low NO*x*	
Maximum Heat Release	27.0 MMBTU/H
Minimum Heat Release (pilot)	0.25 MMBTU/H
Maximum Firing during Start-Up	12.0 MMBTU/H (8:1 Turn Down)
Estimated Footprint	15' × 40'

Example 6

[0036] In another example of a system **2** as described above, undigested wastewater sludge was pyrolyzed and thermally oxidized. Tables 7-9 show a reduction of CECs in the biochar **30** compared to biosolids **12**.

TABLE 7

Pharmaceutical contaminants in biosolids and pyrolysis biochar
SAMPLE ANALYSIS SUMMARY

Parameter	Units	Biosolids	Biochar
Pharmaceutical Analysis			
Bisphenol A	ng/g	1120	ND
Furosemide	ng/g	13	ND
Gemfibrozil	ng/g	248	ND
Glipizide	ng/g	ND	ND
Glyburide	ng/g	ND	ND
Hydrochlorothiazide	ng/g	ND	ND
2-Hydroxy-ibuprofen	ng/g	31.7	ND
Ibuprofen	ng/g	26.8	ND
Naproxen	ng/g	117	ND
Triclocarban	ng/g	150	ND
Triclosan	ng/g	403	ND
Warfarin	ng/g	ND	ND
Acetaminophen	ng/g	621	ND
Azithromycin	ng/g	1490	ND
Caffeine	ng/g	817	ND
Carbadox	ng/g	ND	ND
Carbamazepine	ng/g	9.65	ND
Cefotaxime	ng/g	ND	ND
Ciprofloxacin	ng/g	1240	ND
Clarithromycin	ng/g	66.3	ND
Clinafloxacin	ng/g	ND	ND
Cloxacillin	ng/g	ND	ND
Dehydronifedipine	ng/g	11.6	ND
Diphenhydramine	ng/g	1810	ND
Diltiazem	ng/g	596	ND
Digoxin	ng/g	35.7	ND
Digoxigenin	ng/g	ND	ND
Enrofloxacin	ng/g	ND	ND
Erythromycin-H2O	ng/g	7.25	ND
Flumequine	ng/g	ND	ND
Fluoxetine	ng/g	80.1	ND
Lincomycin	ng/g	ND	ND
Lomefloxacin	ng/g	20	ND
Miconazole	ng/g	593	ND
Norfloxacin	ng/g	ND	ND
Norgestimate	ng/g	ND	ND
Ofloxacin	ng/g	747	ND
Ormetoprim	ng/g	ND	ND
Oxacillin	ng/g	ND	ND
Oxolinic Acid	ng/g	ND	ND
Penicillin G	ng/g	ND	ND
Penicillin V	ng/g	ND	ND
Roxithromycin	ng/g	ND	ND
Sarafloxacin	ng/g	ND	ND
Sulfachloropyridazine	ng/g	ND	ND
Sulfadiazine	ng/g	4.11	ND
Sulfadimethoxine	ng/g	ND	ND
Sulfamerazine	ng/g	ND	ND
Sulfamethazine	ng/g	ND	ND
Sulfamethizole	ng/g	ND	ND
Sulfamethoxazole	ng/g	14.3	ND
Sulfanilamide	ng/g	ND	ND
Sulfathiazole	ng/g	ND	ND
Thiabendazole	ng/g	27.9	ND
Trimethoprim	ng/g	27.5	ND
Tylosin	ng/g	ND	ND
Virginiamycin M1	ng/g	ND	ND
1,7-Dimethylxanthine	ng/g	612	ND

ND = not detected. Below detection limit.

TABLE 8

Contaminants of Polycyclic Aromatic Hydrocarbons
(PAHs) in biosolids and pyrolysis biochar
SAMPLE ANALYSIS SUMMARY

Parameter	Units	Biosolids	Biochar
PAH Analysis			
Acenaphthylene	ng/g	7.03	1.03
Acenaphthene	ng/g	25.7	5.45
Fluorene	ng/g	37.3	1.81
Phenanthrene	ng/g	452	18
Anthracene	ng/g	90.3	2.79
Fluoranthene	ng/g	541	3.5
Pyrene	ng/g	530	5.04
Benz[a]anthracene	ng/g	193	1.3
Chrysene	ng/g	284	2.23
Benzo[b]fluoranthene	ng/g	248	1.05
Benzo[j,k]fluoranthenes	ng/g	190	0.456
Benzo[e]pyrene	ng/g	218	1.42
Benzo[a]pyrene	ng/g	217	1.32
Perylene	ng/g	62.9	ND
Dibenz[a,h]anthracene	ng/g	42.4	0.375
Indeno[1,2,3-cd]pyrene	ng/g	166	1.24
Benzo[ghi]perylene	ng/g	200	1.48
2-Methylnaphthalene	ng/g	35.5	26.4
2,6-Dimethylnaphthalene	ng/g	31.3	4.53
2,3,5-Trimethylnaphthalene	ng/g	61.5	1.86
1-Methylphenanthrene	ng/g	55.6	1.19
Dibenzothiophene	ng/g	30	1.59

ND = not detected. Below detection limit.

TABLE 9

Contaminants of Polychlorinated Biphenyls
(PCBs) in biosolids and pyrolysis biochar
SAMPLE ANALYSIS SUMMARY

Parameter	Units	Biosolids	Biochar
PCB Analysis			
PCB-1	pg/g	99	1.61
PCB-2	pg/g	141	1.42
PCB-3	pg/g	73.8	1.97
PCB-4	pg/g	904	4.11
PCB-5	pg/g	31.9	0.345
PCB-6	pg/g	397	5.15
PCB-7	pg/g	45.9	0.913
PCB-8	pg/g	1190	9.51
PCB-9	pg/g	188	0.929
PCB-10	pg/g	37.5	0.225
PCB-11	pg/g	1590	154
PCB-12 + 13	pg/g	144	3.87
PCB-14	pg/g	2.21	ND
PCB-15	pg/g	545	3.97
PCB-16	pg/g	1330	4.61
PCB-17	pg/g	1210	4.97
PCB-18 + 30	pg/g	1560	9.26
PCB-19	pg/g	470	1.16
PCB-20 + 28	pg/g	3260	11.8
PCB-21 + 33	pg/g	1700	7.05
PCB-22	pg/g	1280	3.98
PCB-23	pg/g	5.95	ND
PCB-24	pg/g	29.7	0.139
PCB-25	pg/g	297	1.17
PCB-26 + 29	pg/g	639	2.23
PCB-27	pg/g	201	0.685
PCB-31	pg/g	2300	10.2
PCB-32	pg/g	394	2.92
PCB-34	pg/g	13.6	ND
PCB-35	pg/g	110	0.214
PCB-36	pg/g	18.4	ND
PCB-37	pg/g	712	2.68
PCB-38	pg/g	1.86	ND
PCB-39	pg/g	23.2	ND
PCB-40 + 41 + 71	pg/g	2070	4.59
PCB-42	pg/g	882	2.16
PCB-43	pg/g	165	0.365
PCB-44 + 47 + 65	pg/g	3940	83.4
PCB-45 + 51	pg/g	904	16.4
PCB-46	pg/g	254	0.679
PCB-48	pg/g	772	1.9
PCB-49 + 69	pg/g	2090	5.58
PCB-50 + 53	pg/g	606	1.63
PCB-52	pg/g	4570	11.8
PCB-54	pg/g	48.9	0.131
PCB-55	pg/g	49.7	0.171
PCB-56	pg/g	1330	2.61
PCB-57	pg/g	13.1	ND
PCB-58	pg/g	4.78	ND
PCB-59 + 62 + 75	pg/g	251	1.21
PCB-60	pg/g	893	1.53
PCB-61 + 70 + 74 + 76	pg/g	5770	10.7
PCB-63	pg/g	118	0.194
PCB-64	pg/g	1490	3.24
PCB-66	pg/g	2520	4.62
PCB-67	pg/g	82.2	0.208
PCB-68	pg/g	37.3	4.8
PCB-72	pg/g	15.9	ND
PCB-73	pg/g	ND	ND
PCB-77	pg/g	240	0.553
PCB-78	pg/g	2.07	ND
PCB-79	pg/g	45.4	ND
PCB-80	pg/g	ND	ND
PCB-81	pg/g	11.6	ND
PCB-82	pg/g	661	1.2
PCB-83 + 99	pg/g	2400	4.19
PCB-84	pg/g	1540	2.44
PCB-85 + 116 + 117	pg/g	899	1.42
PCB-86 + 87 + 97 + 109 + 119 + 125	pg/g	3560	6.46
PCB-88 + 91	pg/g	715	1.23
PCB-89	pg/g	73.7	ND
PCB-90 + 101 + 113	pg/g	4650	7.81
PCB-92	pg/g	633	1.29
PCB-93 + 95 + 98 + 100 + 102	pg/g	4250	6.81
PCB-94	pg/g	37.5	ND
PCB-96	pg/g	45.5	ND
PCB-103	pg/g	33.7	ND
PCB-104	pg/g	9.83	ND
PCB-105	pg/g	1900	3.84
PCB-106	pg/g	ND	ND
PCB-107	pg/g	222	0.424
PCB-108 + 124	pg/g	168	0.353
PCB-110 + 115	pg/g	5130	9.6
PCB-111	pg/g	ND	ND
PCB-112	pg/g	ND	ND
PCB-114	pg/g	131	0.225
PCB-118	pg/g	4150	8.56
PCB-120	pg/g	4.1	ND
PCB-121	pg/g	7.3	ND
PCB-122	pg/g	54.6	ND
PCB-123	pg/g	101	0.184
PCB-126	pg/g	8.15	ND
PCB-127	pg/g	8.67	ND
PCB-128 + 166	pg/g	758	1.51
PCB-129 + 138 + 160 + 163	pg/g	4300	8.35
PCB-130	pg/g	270	0.423
PCB-131	pg/g	74.7	0.12
PCB-132	pg/g	1590	3.01
PCB-133	pg/g	55.4	0.147
PCB-134 + 143	pg/g	261	0.427
PCB-135 + 151 + 154	pg/g	922	2.19
PCB-136	pg/g	611	0.944
PCB-137	pg/g	293	0.544
PCB-139 + 140	pg/g	86.6	0.112
PCB-141	pg/g	748	1.48
PCB-142	pg/g	ND	ND
PCB-144	pg/g	196	0.271
PCB-145	pg/g	3.23	ND
PCB-146	pg/g	464	1.1
PCB-147 + 149	pg/g	ND	5.29
PCB-148	pg/g	8.98	ND
PCB-150	pg/g	11	ND
PCB-152	pg/g	6.02	ND
PCB-153 + 168	pg/g	3200	6
PCB-155	pg/g	82.2	0.176
PCB-156 + 157	pg/g	605	1.11
PCB-158	pg/g	439	0.918
PCB-159	pg/g	ND	ND
PCB-161	pg/g	ND	ND
PCB-162	pg/g	11.1	ND
PCB-164	pg/g	253	0.501
PCB-165	pg/g	ND	ND
PCB-167	pg/g	174	0.378
PCB-169	pg/g	ND	ND
PCB-170	pg/g	698	1.4
PCB-171 + 173	pg/g	230	0.474
PCB-172	pg/g	36.5	0.255
PCB-174	pg/g	727	1.39
PCB-175	pg/g	31.4	ND
PCB-176	pg/g	99.6	0.145
PCB-177	pg/g	397	0.812
PCB-178	pg/g	150	0.161
PCB-179	pg/g	316	0.527
PCB-180 + 193	pg/g	1680	3.35
PCB-181	pg/g	10.8	ND
PCB-182	pg/g	ND	ND
PCB-183 + 185	pg/g	505	1.04
PCB-184	pg/g	69.8	0.211
PCB-186	pg/g	0.434	ND
PCB-187	pg/g	889	1.7

TABLE 9-continued

Contaminants of Polychlorinated Biphenyls
(PCBs) in biosolids and pyrolysis biochar
SAMPLE ANALYSIS SUMMARY

Parameter	Units	Biosolids	Biochar
PCB-188	pg/g	2.56	ND
PCB-189	pg/g	28.4	0.105
PCB-190	pg/g	147	0.273
PCB-191	pg/g	26.5	ND
PCB-192	pg/g	ND	ND
PCB-194	pg/g	338	0.757
PCB-195	pg/g	103	0.198
PCB-196	pg/g	170	0.3
PCB-197 + 200	pg/g	61.3	0.161
PCB-198 + 199	pg/g	519	0.978
PCB-201	pg/g	58.9	0.164
PCB-202	pg/g	118	0.258
PCB-203	pg/g	316	0.565
PCB-204	pg/g	5.59	ND
PCB-205	pg/g	16.3	ND
PCB-206	pg/g	348	0.501
PCB-207	pg/g	37.9	ND
PCB-208	pg/g	112	0.178
PCB-209	pg/g	166	0.409
Total Monochloro Biphenyls	pg/g	314	5
Total Dichloro Biphenyls	pg/g	5080	179
Total Trichloro Biphenyls	pg/g	15600	61.6
Total Tetrachloro Biphenyls	pg/g	29200	157
Total Pentachloro Biphenyls	pg/g	31400	51.2
Total Hexachloro Biphenyls	pg/g	18500	30.1
Total Heptachloro Biphenyls	pg/g	6040	10.6
Total Octachloro Biphenyls	pg/g	1710	0.258
Total Nonachloro Biphenyls	pg/g	498	0.501
Decachloro Biphenyl	pg/g	166	0.409
TOTAL PCBs	pg/g	108000	496
Aroclor 1016	pg/g	ND	ND
Aroclor 1221	pg/g	ND	ND
Aroclor 1232	pg/g	ND	ND
Aroclor 1242	pg/g	24900	122
Aroclor 1248	pg/g	ND	ND
Aroclor 1254	pg/g	47700	51.7
Aroclor 1260	pg/g	14400	29
2,3,7,8-TCDD	pg/g	ND	ND
1,2,3,7,8-PECDD	pg/g	ND	ND
1,2,3,4,7,8-HXCDD	pg/g	0.769	ND
1,2,3,6,7,8-HXCDD	pg/g	2.79	ND
1,2,3,7,8,9-HXCDD (225)	pg/g	1.57	ND
1,2,3,7,8,9-HXCDD	pg/g	2.38	ND
1,2,3,4,6,7,8-HPCDD	pg/g	95.4	ND
OCDD	pg/g	1790	ND
2,3,7,8-TCDF (225)	pg/g	0.963	ND
2,3,7,8-TCDF	pg/g	2.57	ND
1,2,3,7,8-PECDF	pg/g	0.405	ND
2,3,4,7,8-PECDF	pg/g	0.647	ND
1,2,3,4,7,8-HXCDF	pg/g	ND	ND
1,2,3,6,7,8-HXCDF	pg/g	1.26	ND
1,2,3,7,8,9-HXCDF	pg/g	ND	ND
2,3,4,6,7,8-HXCDF	pg/g	0.849	ND
1,2,3,4,6,7,8-HPCDF	pg/g	20.9	ND
1,2,3,4,7,8,9-HPCDF	pg/g	1.08	ND
OCDF	pg/g	42.8	ND
TOTAL TETRA-DIOXINS	pg/g	5.69	ND
TOTAL PENTA-DIOXINS	pg/g	10.9	ND
TOTAL HEXA-DIOXINS	pg/g	27.6	ND
TOTAL HEPTA-DIOXINS	pg/g	193	ND
TOTAL TETRA-FURANS	pg/g	10.7	ND
TOTAL PENTA-FURANS	pg/g	12.6	ND
TOTAL HEXA-FURANS	pg/g	16	ND
TOTAL HEPTA-FURANS	pg/g	38	ND

ND = not detected. Below detection limit.

[0037] Unless stated otherwise or apparent from the context, solids contents or concentrations mentioned above are total solids (TS) measurements, which would be the same as a dried solids (DS) measurement. In digestate, the DS is roughly 10% higher than total suspended solids (TSS) and the total dissolved solids (TDS) is typically 2500 to 4000 mg/L (0.25 to 0.4%). For example, a 5% DS digestate may have 46,000 mg/L of TSS and 4000 mg/L TDS. Accordingly, solids contents or concentrations, unless specified otherwise, can generally be interpreted as TSS without causing a material difference in the process.

[0038] The descriptions of processes and apparatus above are to provide at least one example of an embodiment within each claim but not to limit or define any claim. However, multiple processes and apparatus have been described above and it is possible that a particular process or apparatus described above is not within a specific claim. Process parameters are given as examples of how a plant may be operated and are not meant to limit a claim unless explicitly recited in a claim. Other processes for similar applications might operate at parameters within ranges that are 50% or 100% larger in both directions than the parameter ranges described above, or within a 50% or 100% variation from a single parameter described above. If one or more elements or steps described above are used to treat other wastes or under other conditions, then one or more process ranges described above might not be suitable and would be substituted with other appropriate parameters. Words such as “may”, “preferable” or “typical”, or variations of them in the description above, indicate that a process step or apparatus element is possible, preferable or typical, according to the word used, but still optional and not necessarily part of any claimed invention unless explicitly included in a claim.

What is claimed is:

1. A process for treating organic waste, comprising the steps of

volatizing at least a portion of the organic waste; and

oxidizing the gas.

2. The process of claim **1**, wherein the volatizing step comprises pyrolysing and/or gasifying the at least a portion of the organic waste.

3. The process of claim **1** or **2**, wherein the volatizing step comprises volatizing Perfluoroalkyl substances (PFAS) compounds and/or Contaminants of Emerging Concern (CECs), such as pharmaceutical contaminants, Polychlorinated Biphenyls (PCBs), and Polycyclic Aromatic Hydrocarbons (PAHs), from the organic waste.

4. The process of any one of claims **1-3**, wherein the temperature of the volatizing step is from about 300 to about 850 degrees C.

5. The process of any one of claims **1-4**, wherein the volatizing step is conducted at a residence time of from about 10 to about 90 minutes.

6. The process of any one of claims **1-5**, wherein the temperature of the oxidizing step is from about 700 to about 1350 degrees C.

7. The process of any one of claims **1-6**, wherein the oxidizing step is conducted at a residence time from about 0.1 to about 10.0 seconds.

8. The process of any one of claims **1-6**, wherein the biochar portion produced in the volatizing step has a PFAS compound content of less than about 6 ng/g, less than about 4 ng/g, less than about 3 ng/g, less than about 2 ng/g, below detection limits, or less than about 2.5 ppb (PFOA) and/or less than about 5.2 ppb (PFOS).

9. The process of any one of claims **1-7**, wherein the biochar portion produced in the volatizing step has a Perfluoroalkyl substances (PFAS) compound and/or Contaminants of Emerging Concern (CECs), such as pharmaceutical contaminants, Polychlorinated Biphenyls (PCBs), and Polycyclic Aromatic Hydrocarbons (PAHs) content reduced by about 75%, about 80%, about 85%, about 90%, about 95%, about 97%, about 98%, about 99%, or 100% in comparison to the Perfluoroalkyl substances (PFAS) compound and/or Contaminants of Emerging Concern (CECs), such as pharmaceutical contaminants, Polychlorinated Biphenyls (PCBs), and Polycyclic Aromatic Hydrocarbons (PAHs) content before the volatizing step.

10. The process of any one of claims **1-9**, wherein the biochar or char portion produced in the volatizing step is a class A biosolid.

11. The process of any one of claims **1-10**, further comprising recovering energy from the flue gas produced from the oxidation step.

12. The process of any one of claims **1-11**, wherein the organic waste comprises wastewater treatment primary or secondary sludge, source separated organics (SSO), food waste, the organic fraction of municipal solid waste, yard waste, industrial or commercial waste, or agricultural waste, or any combination thereof.

13. The process of any one of claims **1-10**, wherein organic waste comprises biosolids.

14. The process of claim **12** or **13**, wherein the process further comprises drying the biosolids before the volatizing step.

15. The process of claim **14**, wherein the dried biosolids comprises from about 15 ppb to about 30 ppb of PFAS compounds.

16. The process of claim **14** or **15**, further comprising exchanging heat from the flue gas produced during the oxidation step.

17. The process of claim **16**, further comprising using the exchanged heat for volatizing the organic waste and/or for drying the biosolids.

18. The process of any one of claims **1-17**, further comprising treating the flue gas produced during the oxidation step to remove NOx and/or SOx.

19. The process of claim **18**, further comprising exchanging heat between removing NOx and SOx.

20. A system for treating organic waste, comprising:

a volatilization reactor; and

a thermal oxidizer.

21. The system of claim **20**, wherein the volatilization reactor is a pyrolysis reactor or a gasification reactor.

22. The system of claim **20** or **21**, wherein the volatilization reactor has an outlet and the thermal oxidizer has an inlet, and wherein the outlet of the volatilization reactor is connected to the inlet of the thermal oxidizer.

23. The system of any one of claims **20-22**, wherein the thermal oxidizer receives gas from the volatilization reactor.

24. The system of any one of claims **20-23**, further comprising a dryer in communication with the volatilization reactor.

25. The system of any one of claims **20-24**, further comprising a heat exchanger in thermal communication with the thermal oxidizer.

26. The system of claim **24** or **25**, wherein the heat exchanger is in thermal communication with the dryer.

27. The system of any one of claims **24-26**, wherein the heat exchanger is in thermal communication with the volatilization reactor.

28. The system of any one of claims **24-27**, further comprising a second heat exchanger in thermal communication with the volatilization reactor and the dryer.

29. The system of any one of claims **20-28**, further comprising a gas treatment unit, for example, a NOx and/or a SOx treatment unit, in communication with the thermal oxidizer.

30. The system of claim **29**, further comprising a heat exchanger in thermal communication with the NOx and/or SOx treatment unit, for example, between the NOx and SOx treatment units.

31. The system of any one of claims **20-30**, wherein the volatilization reactor is capable of volatizing Perfluoroalkyl substances (PFAS) compounds and/or Contaminants of Emerging Concern (CECs), such as pharmaceutical contaminants, Polychlorinated Biphenyls (PCBs), and Polycyclic Aromatic Hydrocarbons (PAHs), from the organic waste.

32. The system of any one of claims **20-31**, wherein the biochar portion produced in the volatilization reactor has a Perfluoroalkyl substances (PFAS) compound and/or Contaminants of Emerging Concern (CECs), such as pharmaceutical contaminants, Polychlorinated Biphenyls (PCBs), and Polycyclic Aromatic Hydrocarbons (PAHs) content reduced by about 75%, about 80%, about 85%, about 90%, about 95%, about 97%, about 98%, about 99%, or 100% in comparison to the Perfluoroalkyl substances (PFAS) compound and/or Contaminants of Emerging Concern (CECs), such as pharmaceutical contaminants, Polychlorinated Biphenyls (PCBs), and Polycyclic Aromatic Hydrocarbons (PAHs) content before volatilization.

33. A process for treating organic waste, comprising the steps of

oxidizing a volatized portion of organic waste.

34. The process of claim **33**, wherein the volatized portion comprises Perfluoroalkyl substances (PFAS) compounds and/or Contaminants of Emerging Concern (CECs), such as pharmaceutical contaminants, Polychlorinated Biphenyls (PCBs), and Polycyclic Aromatic Hydrocarbons (PAHs), from the organic waste.

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