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GAS COLLECTION

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(54) **GAS COLLECTION**

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C12M 3/00 (2006.01)
G05D 11/00 (2006.01)
G05D 11/04 (2006.01)
G05D 7/03 (2006.01)

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CPC **G05D 11/003** (2013.01); **G05D 7/03** (2013.01); **G05D 11/04** (2013.01)

(58) **Field of Classification Search**
CPC G05D 11/003; G05D 7/03; G05D 11/04
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,162,556 A * 12/2000 Vollmar H01M 8/0612
429/411
2006/0006055 A1* 1/2006 Bonde B01D 3/346
203/73
2010/0018228 A1* 1/2010 Flammang F25B 27/02
62/115
2012/0137977 A1* 6/2012 Hermes A01K 61/02
119/6.5

OTHER PUBLICATIONS

G. Irvine, E. R. Lamont, and B. Antizar-Ladislao; Energy from Waste: Reuse of Compost Heat as a Source of Renewable Energy; International Journal of Chemical Engineering; vol. 2010, Article ID 627930; 10 pages.

* cited by examiner

Primary Examiner — William H Beisner

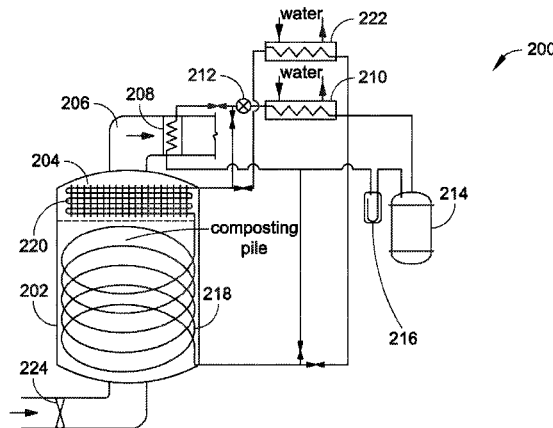
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(57) **ABSTRACT**

A system includes a vessel configured to couple with a gas source for drawing gas into the vessel. The vessel is also configured to receive liquid. The system includes an overflow port in fluid communication with the environment external to the vessel. The overflow port is configured to separate gas within the vessel from the external environment. The system also includes an overflow conduit having an end within the overflow port so that when gas pressure within the vessel increases, liquid is received by the overflow conduit. Another system includes a tank defining an air space for receiving gas generated during the biodegradation of biomass feedstock. The second system also includes an exhaust port, a first evaporator, a first condenser, an expansion valve, and a compressor. The second system also includes a heat exchanger, a second evaporator, and a second condenser.

3 Claims, 8 Drawing Sheets



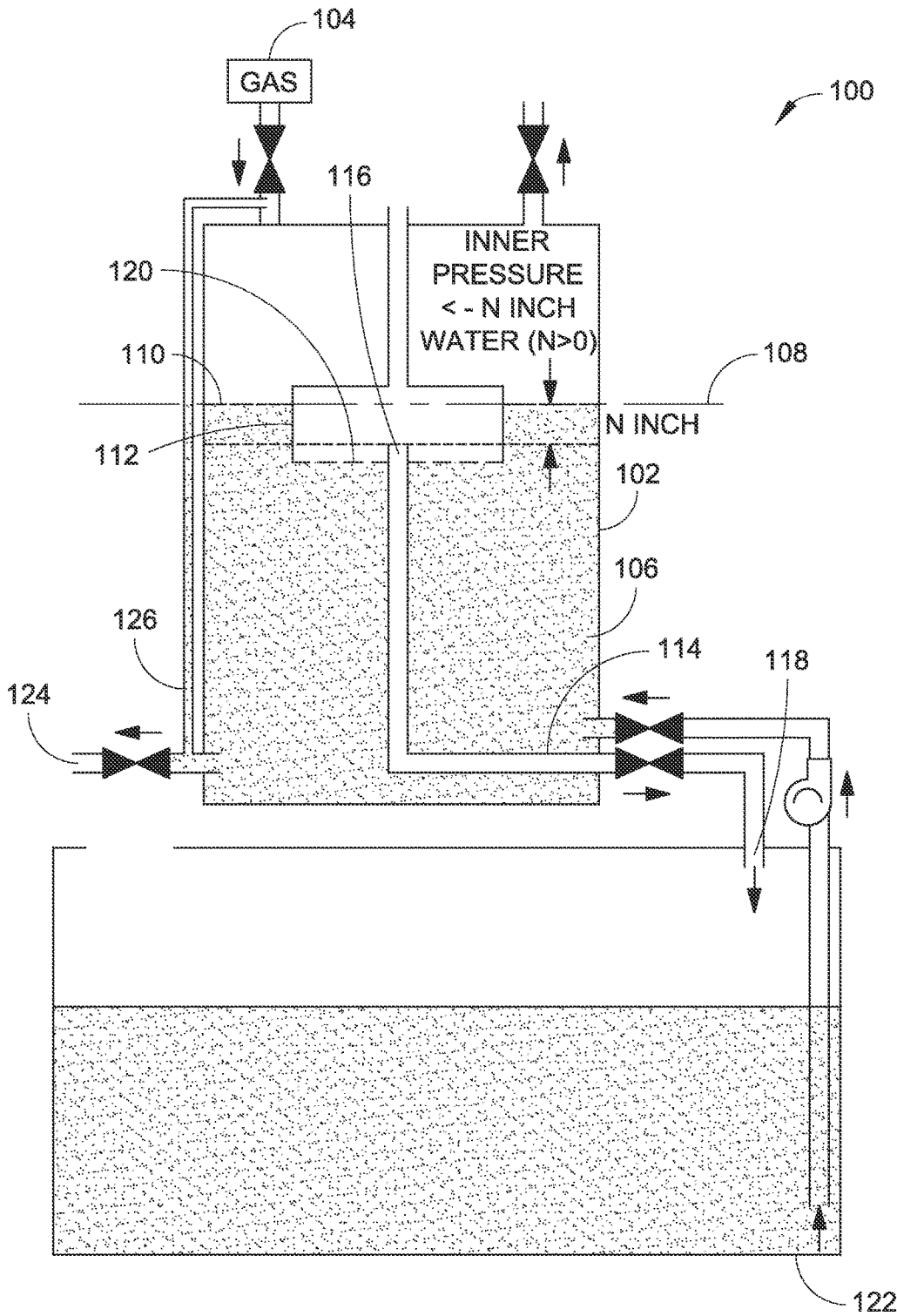


FIG. 1A

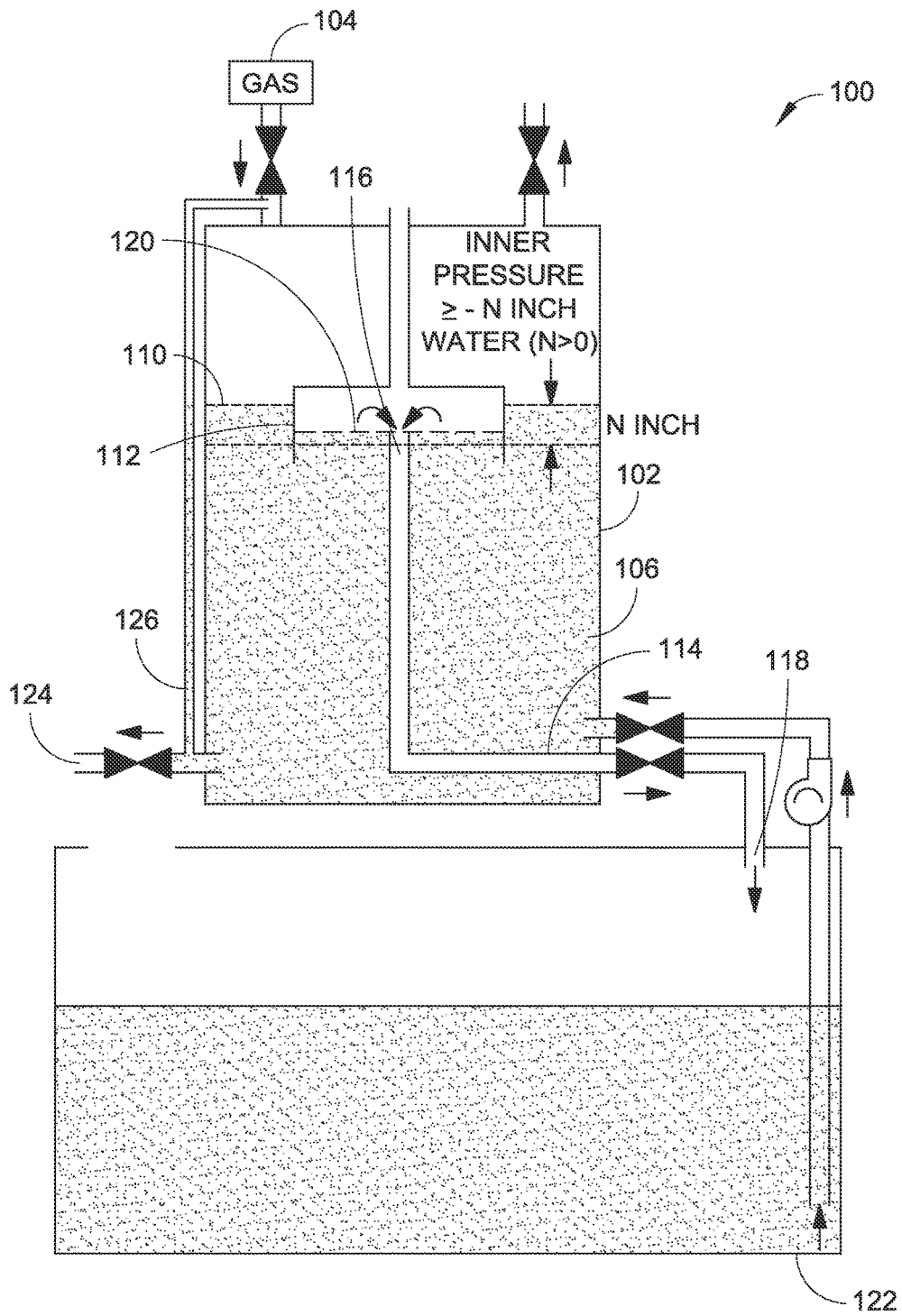


FIG. 1B

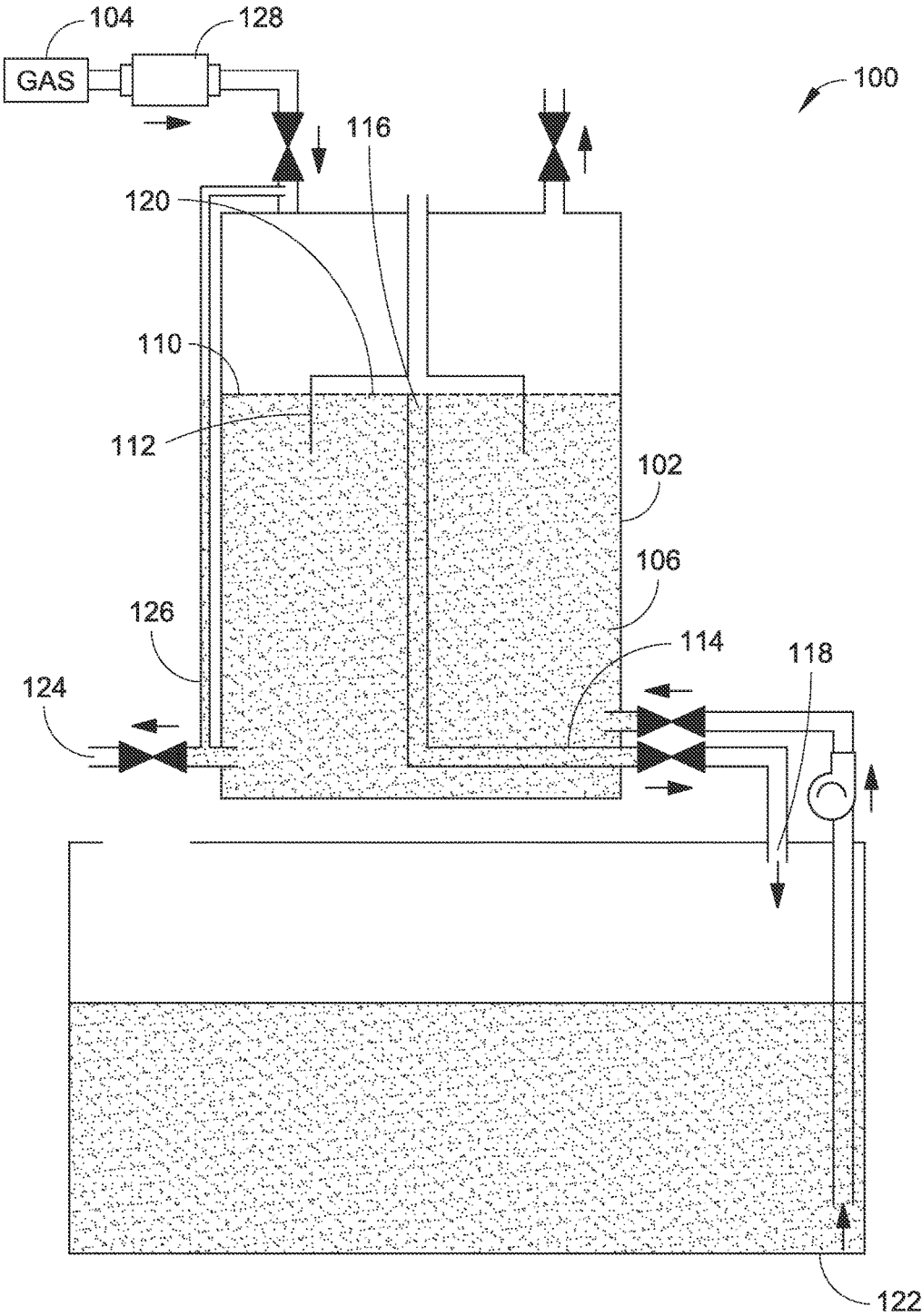


FIG. 2

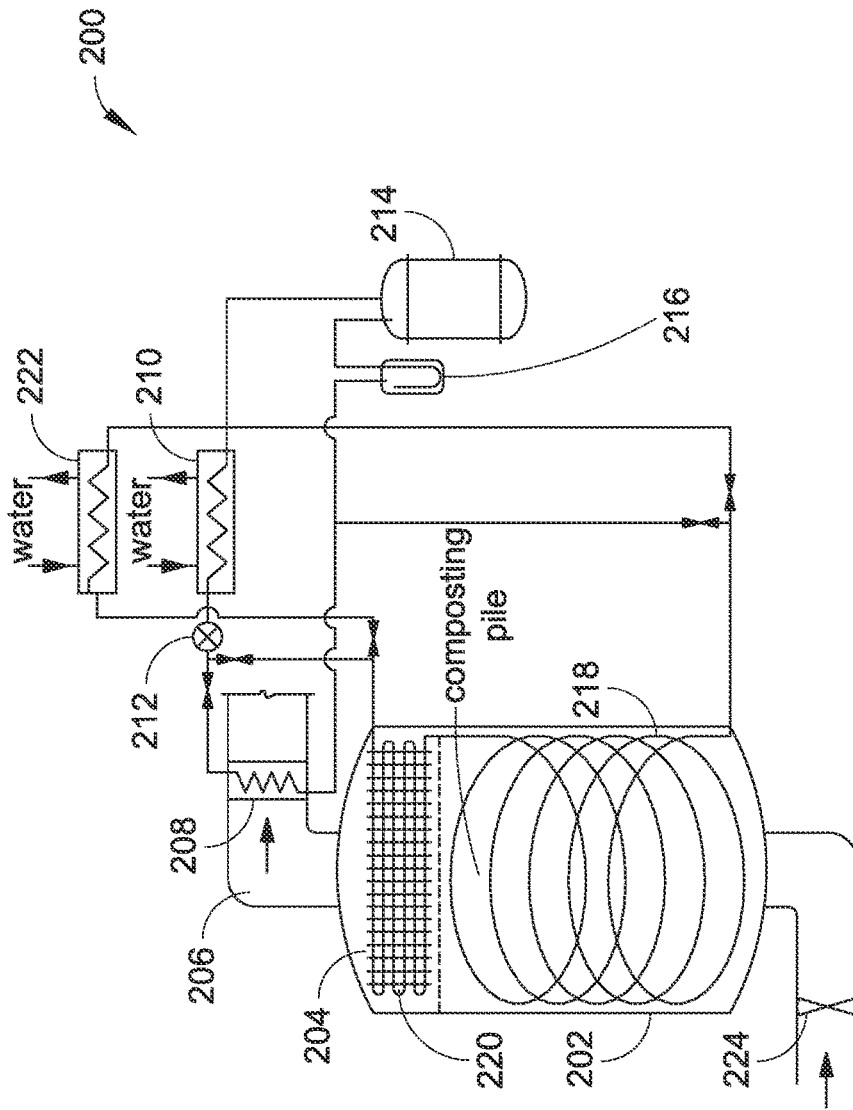


FIG. 3

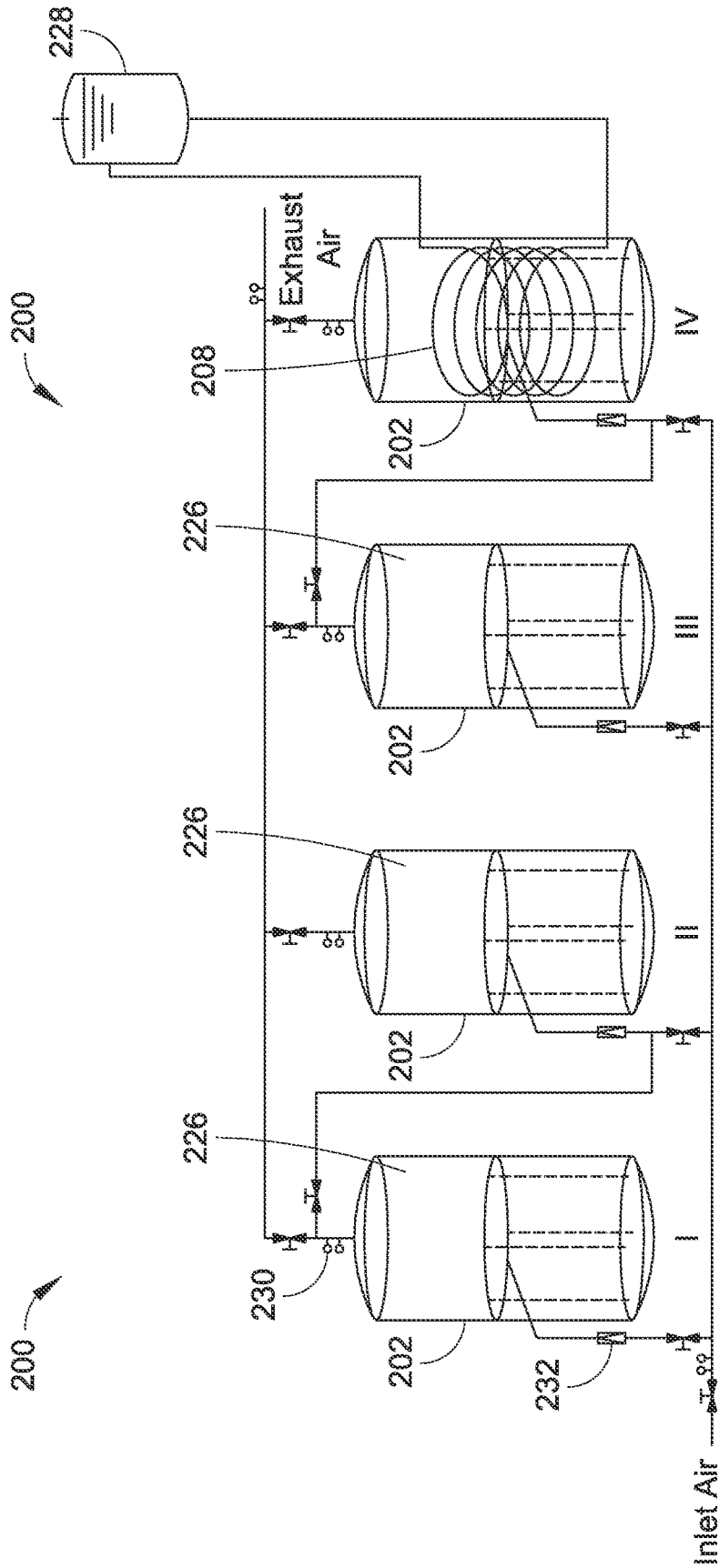


FIG. 4

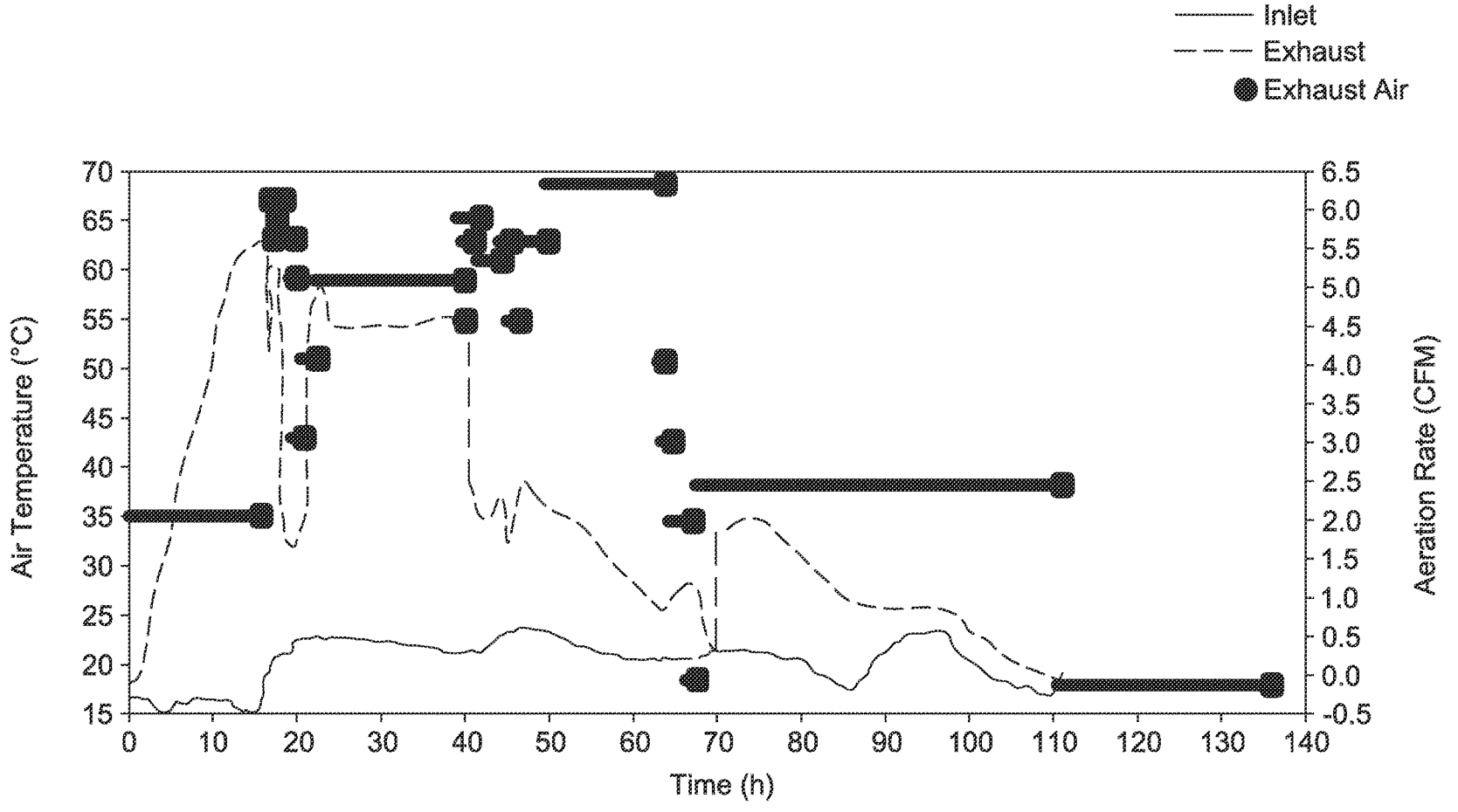


FIG. 5

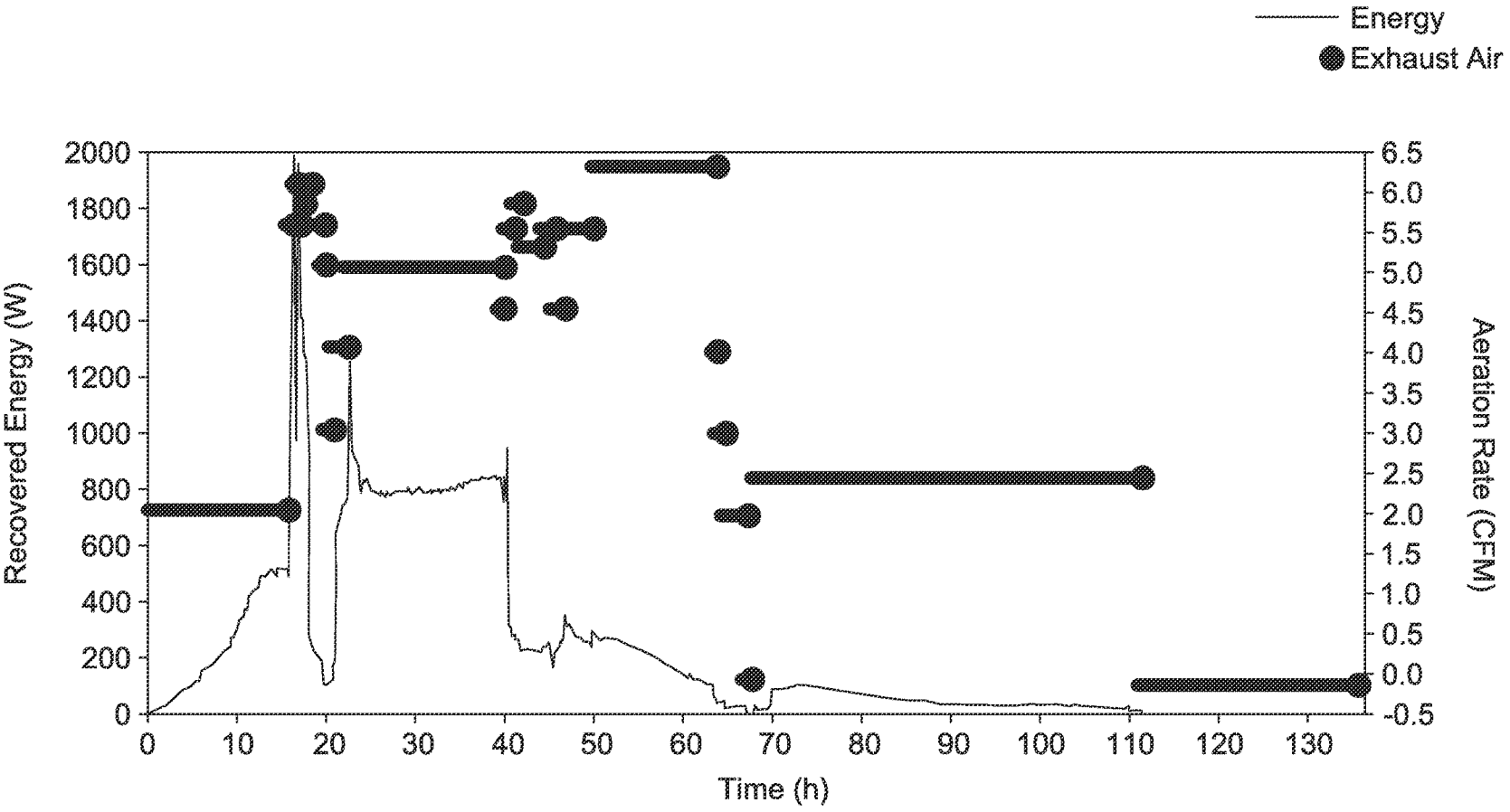


FIG. 6

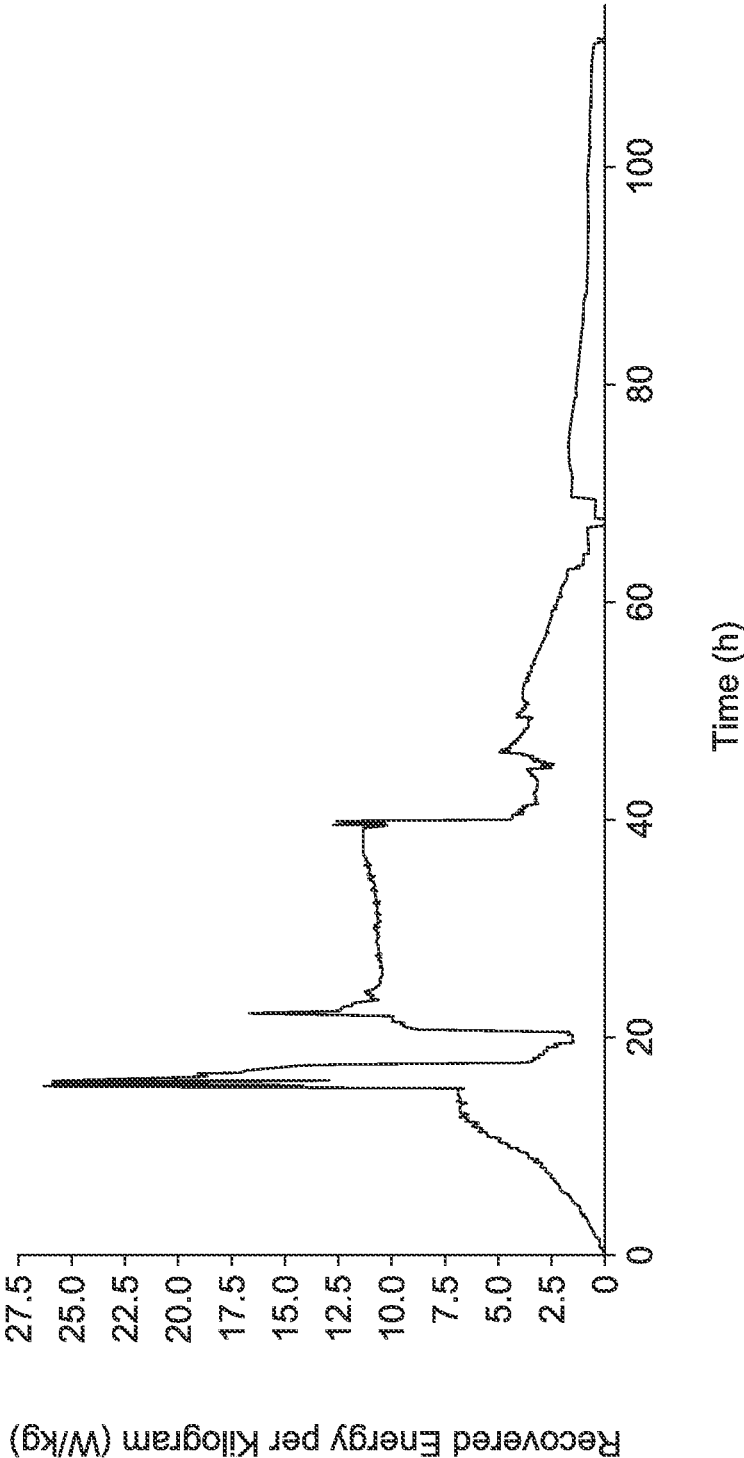


FIG. 7

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GAS COLLECTIONCROSS-REFERENCE TO RELATED
APPLICATIONS

The present application claims the benefit under 35 U.S.C. §119(e) of U.S. Provisional Application Ser. No. 61/668,098, filed Jul. 5, 2012, and titled "Gas Collection System," which is herein incorporated by reference in its entirety.

BACKGROUND

As energy prices, environmental pollution, population growth, waste generation rate, and concerns regarding greenhouse-gas emissions continue to rise worldwide, there is an increasing desire for renewable energy and alternative energy and waste treatment solutions.

SUMMARY

A system includes a vessel configured to couple with a gas source for drawing gas into the vessel. The vessel is also configured to receive liquid. The system includes an overflow port in fluid communication with the environment external to the vessel. The overflow port is configured to separate gas within the vessel from the external environment and sustain gas pressure within the vessel. The system also includes an overflow conduit having an end within the overflow port so that when gas pressure within the vessel increases, liquid is received by the overflow conduit. The liquid can be drained through the overflow conduit to a water recycling tank. In some embodiments, real-time gas volume within the system is obtained (e.g., by metering the water level in the water recycling tank).

A system includes a tank defining an air space for receiving gas (e.g., hot air) generated during the biodegradation (e.g., aerobic biodegradation) of biomass feedstock. The system also includes an exhaust port configured to exhaust the gas from the air space of the tank. The system further includes a first evaporator coupled with the exhaust port, a first condenser coupled with the first evaporator, an expansion valve coupled between the first evaporator and the first condenser, and a compressor coupled with the first condenser. The system also includes a heat exchanger disposed of the tank for exchanging heat with the biomass feedstock during the biodegradation of the biomass feedstock, a second evaporator disposed in the air space defined by the tank and coupled with the heat exchanger, and a second condenser coupled with the second evaporator.

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

DRAWINGS

The Detailed Description is described with reference to the accompanying figures. The use of the same reference numbers in different instances in the description and the figures may indicate similar or identical items.

FIG. 1A is a diagrammatic illustration of a system configured to collect gas, such as biogas generated from the biodegradation of biomass waste, where an initial negative

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gas pressure is established within a vessel sealably coupled with a gas source in accordance with example embodiments of the present disclosure.

FIG. 1B is a diagrammatic illustration of the system illustrated in FIG. 1A, where the gas pressure within the vessel increases, and a portion of liquid in the vessel is received by an overflow conduit in accordance with example embodiments of the present disclosure.

FIG. 2 is a diagrammatic illustration of another system configured to collect gas, such as biogas generated from the biodegradation of biomass waste, where an initial active gas pressure is established within a vessel sealably coupled with a gas source using a vacuum source in accordance with example embodiments of the present disclosure.

FIG. 3 is a diagrammatic illustration of a system implementing a heat pump for biomass energy recovery (e.g., for supplying hot water, space heating, and so forth) in accordance with example embodiments of the present disclosure.

FIG. 4 is a diagrammatic illustration of a composting system configured for biomass energy recovery in accordance with example embodiments of the present disclosure.

FIG. 5 is a graph illustrating exhaust and inlet air temperatures for a composting system configured for biomass energy recovery, such as the composting system illustrated in FIG. 4, in accordance with example embodiments of the present disclosure.

FIG. 6 is a graph illustrating recovered energy from biomass degradation for a composting system, such as the composting system illustrated in FIG. 4, in accordance with example embodiments of the present disclosure.

FIG. 7 is a graph illustrating recovered energy per kilogram of biomass for a composting system, such as the composting system illustrated in FIG. 4, in accordance with example embodiments of the present disclosure.

DETAILED DESCRIPTION

In 2009, more than two hundred and fifty (250) million tons of municipal solid waste (MSW) was generated. Over two-thirds of this waste was comprised of organic material. However, only about seven percent (7%) of the waste was composted to produce fertilizers and so forth. The majority of biomass waste is placed in landfills or incinerated. Biodegradation provides ecologically and/or environmentally friendly techniques for handling biomass solid wastes, such as organic MSW. For example, biomass biodegradation can reduce environmental effects of biomass wastes (e.g., by neutralizing carbon and/or reducing sulfur, nitrogen oxides, methane emissions, and so forth). Further, biodegradation of biomass solid waste can be used to produce bio-fertilizers, which can be used to promote healthy and fertile soils for improved agricultural productivity, food production, and so forth. Additionally, biogas generated during, for instance, anaerobic digestion of biomass can be used to provide heat and/or power. Still further, biodegradation can be used to conserve landfill space, reduce disposal costs of biomass waste, produce a useful end product, and so forth.

Referring generally to FIGS. 1A through 2, a system **100** for collecting gas, such as biogas generated from the biodegradation of biomass waste is described. The system **100** includes a vessel **102** configured to sealably couple with a gas source **104**, such as a source of biogas from the biodegradation of biomass waste. As shown in FIG. 1A, an initial negative gas pressure is established within the vessel **102** with respect to the gas source **104** for drawing gas from the gas source **104** into the vessel **102**. The vessel **102** is also configured to receive a liquid **106** (e.g., water) having an

initial liquid level **108** at an interface **110** between the liquid **106** and the gas when the initial negative gas pressure is established within the vessel **102**. The system **100** also includes an overflow port **112** in fluid communication with the environment external to the vessel **102** (e.g., via an atmospheric pressure conduit or the like). The overflow port **112** is configured to separate gas within the vessel **102** from the external environment. The system **100** further includes an overflow conduit **114** having a first end **116** and a second end **118**. The first end **116** of the overflow conduit **114** is disposed within the overflow port **112** beneath the initial liquid level **108**. In this manner, after the initial negative gas pressure is established within the vessel **102**, when the gas pressure within the vessel **102** increases and a liquid level **120** in the overflow port **112** extends above the first end **116** of the overflow conduit **114**, a portion of the liquid **106** is received by the overflow conduit **114**.

In some embodiments, the system **100** includes a liquid reservoir **122** coupled with the vessel **102**. In this configuration, the vessel **102** is configured to receive liquid **106** from the liquid reservoir **122**, and the liquid reservoir **122** is configured to receive liquid **106** from the vessel **102** (e.g., when the gas pressure within the vessel **102** increases and the liquid level **120** in the overflow port **112** extends above the first end **116** of the overflow conduit **114**). For example, the liquid reservoir **122** is coupled with the second end **118** of the overflow conduit **114** for receiving liquid **106** from the overflow conduit **114**. In embodiments of the disclosure, the system **100** includes a liquid outlet **124** disposed proximate to the bottom of the vessel **102**. In some embodiments, the system **100** includes a liquid level indicator **126** coupled between the vessel **102** and the gas source **104**. In some embodiments, the system **100** includes a vacuum source **128** coupled with the vessel **102**. The vacuum source **128** is configured to couple the vessel **102** with the gas source **104** for establishing the initial negative gas pressure within the vessel **102**.

In embodiments of the disclosure, systems **100** implement fast, low-cost, scalable biomass waste anaerobic biodegradation systems that produce sustainable biogas energy and bio-fertilizers. The systems **100** use fast aerobic biodegradation technology as a pretreatment method to effectively break down complex compounds of biomass waste to readily biodegradable products, which can significantly increase the anaerobic biodegradation rate. Further the systems **100** can use multiple types of biomass wastes. In some embodiments, systems **100** provide a sustainable biogas yield rate of between approximately one and forty one-hundredths liters per day of liter-wet biomass (1.40 L/day·L-wet biomass) and one and eighty one-hundredths liters per day of liter-wet biomass (1.80 L/day·L-wet biomass). Further, in some embodiments the systems **100** provide a total volatile solids removal efficiency between approximately sixty percent (60%) and eighty percent (80%) within approximately ten (10) days. In this manner, biogas energy is generated for heat and/or power, reducing natural gas or electricity usage, minimizing capital investment, reducing resources usage for biogas energy plants, improving organic waste management, and/or quickly delivering healthy and fertile slurry.

The systems **100** provide low-cost, scalable, negative-pressure gas collection systems, which create a negative pressure condition within an anaerobic biodegradation system to effectively migrate the biogas into the collection system. The systems **100** can produce biogas energy, bio-fertilizers, and so forth.

Regarding concerns about odor complaints and environmental risks, gas collection technologies for effectively

migrating explosive biogas from the anaerobic biodegradation systems are desirable. Currently, biogas is mainly collected by a passive or active-pressure gas collection system. However, these systems are often problematic, relatively inefficient, and/or relatively costly.

A passive-pressure gas collection system uses existing pressure variations in an anaerobic biodegradation system to vent biogas into control systems (e.g., flare, incinerators, boilers, gas turbines, and so forth). Thus, the efficiency of a passive-pressure biogas collection system generally depends on the overall biogas generation rate, and how the inner biogas release fittings of the anaerobic biodegradation system are implemented. Although the inner biogas release fittings can be lined throughout the anaerobic biodegradation system covering the top, bottom and sides of a container, biogas migration efficiency is not necessarily stable. Often, the biogas becomes trapped under the clay or geo-synthetic membranes of biomass feedstock with large-scale impermeable areas in the anaerobic biodegradation system, and biogas pressure is unable to push the gas into the collection system. Thus, biogas collection efficiency is reduced and anaerobic biodegradation is inhibited.

Typical active-pressure collection systems that use gas-moving equipment, like a vacuum, are relatively costly compared with a passive-pressure gas collection system. On the other hand, current gas collection systems, including both passive- and active-pressure collection systems, directly vent the biogas to control systems or the atmosphere. Further, these configurations lack stable sampling and analysis sub-collection systems for enabling ease of performance analysis.

Additionally, with passive-pressure gas collection systems, high barometric pressure can result in outside air entering the anaerobic biodegradation energy system through passive vents that are not routing gas to control devices. Consequently, with the oxygen mixed into the anaerobic biodegradation energy system, the biogas generation rate can be reduced significantly. These configurations provide slower degradation, longer retention time, larger energy systems, and greater capital investment, with smaller energy output. Thus, typical gas collection systems are often relatively inefficient, costly, and not considered reliable enough for use to vent biogas.

In order to migrate the biogas produced by the biomass waste anaerobic degradation system in a fast and stable manner, systems **100** implement low-cost, scalable, negative-pressure biogas or active-pressure collection systems using water displacement via the vessel **102** (e.g., a gas collection bucket), the liquid reservoir **122** (e.g., a water recycling tank), and possibly the vacuum source **128** (e.g., gas-moving equipment).

The systems **100** can be implemented using, for example, modular industrial components to ensure market-leading performance, scalability and service integration. The overflow port **112** implements an inner auto overflow structure (e.g., an inverted plastic bottle) within the gas collection bucket to create a negative pressure condition to effectively migrate the biogas from the anaerobic biodegradation system to the gas collection bucket. The inverted plastic bottle obtains atmospheric pressure for the space at the top and overflows the displaced water to the water recycling tank from the bottom at steady status. In some embodiments, gas-moving equipment (e.g., vacuum source **128**) is used to create a low pressure condition to effectively migrate the biogas from the anaerobic biodegradation system to the gas collection bucket.

In the initial condition as shown in FIG. 1A, the inner pressure of the gas collection bucket is regulated to lower than $-n$ inch water pressure ($n>0$), the water level in the inverted plastic bottle is lower than the inlet of the overflow conduit **114** (e.g., an overflow pipe). As biogas is created, inner pressure of the gas collection bucket increases to higher than $-n$ inch water pressure, the water level in the inverted plastic bottle moves to higher than the inlet of the overflow pipe, the gas then displaces the water. The volume of gas can be determined by using the water level difference and the cross-sectional area of the gas collection bucket or the amount of water that is displaced by the gas for performance analysis. In addition, a water recycling tank is used to re-use and save the displaced water.

In this manner, the gas collection systems **100** migrate biogas produced from anaerobic biodegradation energy systems and generate environmental benefits, such as collecting the biogas in a fast, low-cost, and stable manner, and assisting the development of anaerobic biodegradation technology for producing biogas energy and bio-fertilizers; reducing environmental impacts from biogas emissions through the reduction of ozone precursors (volatile organic compounds and nitrogen oxides), methane, and odorous compounds; meeting government laws and regulations regarding operations and management of biogas production; and so forth.

Referring generally to FIGS. 3 through 7, a system **200** for recovering energy from biomass degradation (e.g., for supplying hot water, space heating, and so forth) is described. The system **200** includes a tank **202** (e.g., a reactor) configured to receive biomass feedstock for biodegradation. The tank **202** defines an air space **204** for receiving gas (e.g., biogas) generated during the biodegradation of the biomass feedstock. The system **200** also includes an exhaust port **206** coupled with the tank **202**. The exhaust port **206** is configured to exhaust the gas generated during the biodegradation of the biomass feedstock from the air space **204** of the tank **202**. The system **200** further includes a first evaporator **208** coupled with the exhaust port **206** for recovering heat from the exhaust gas. The system **200** also includes a first condenser **210** coupled with the first evaporator **208**. In embodiments of the disclosure, an expansion valve **212** is coupled between the first evaporator **208** and the first condenser **210**. The system **200** further includes a compressor **214** coupled with the first condenser **210**. In some embodiments, the system **200** also includes a separator **216** for separating gas from liquid. The separator **216** is coupled between the compressor **214** and the first evaporator **208**.

The system **200** includes a heat exchanger **218** (e.g., a coil heat exchanger) disposed of the tank **202** for exchanging heat with the biomass feedstock during the biodegradation of the biomass feedstock. The system **200** also includes a second evaporator **220** disposed in the air space **204** defined by the tank **202**. The second evaporator **220** is coupled with the heat exchanger **218** for recovering heat from the gas generated during the biodegradation of the biomass feedstock. The system **200** further includes a second condenser **222** coupled with the second evaporator **220**. In some embodiments, the system **200** also includes a mechanical ventilator **224** (e.g., one or more fans) in fluid communication with the tank **202**. The mechanical ventilator **224** is configured to supply air to facilitate the biodegradation of the biomass feedstock. For example, the system **200** includes an air supply grille allowing the mechanical ventilator **224** to draw inlet/supply air into the system **200**.

Regarding energy consumption, buildings represent about thirty-nine percent (39%) of primary energy, seventy-four

percent (74%) of electricity consumption, and thirty-nine percent (39%) of carbon emissions in the United States. Thus, effective waste management and renewable energy sources are important issues. However, typical waste treatment technologies have adverse effects on the environment, do not recycle useful materials, and/or do not reclaim the energy from waste. Generally, typical methods of solid waste treatment include landfills, mechanical heat treatment, and composting. The disposal of wastes in landfills generates methane that has a high global warming potential, while mechanical heat treatment requires specific facilities and may release undesirable gases. Thus, there is a need for effective mitigation of greenhouse gas emissions and reduction of residual containments, which could provide significant environmental benefits and sustainable development.

Composting is an effective method to handle municipal waste. Composting conserves landfill space, reduces disposal cost, and produces a useful end-product. There are large amounts of energy contained in wastes. For instance, gross calorific values (GCV) of kitchen wastes, papers and cards, and garden wastes are approximately fifteen and seven-tenths gigajoules per ton (15.7 GJ/t), seventeen and four-tenths gigajoules per ton (17.4 GJ/t), and sixteen and one-tenth gigajoules per ton (16.1 GJ/t), respectively. In the United States, there were about thirty-two and nine-tenths million tons (32.9 M tons) of yard trimmings in 2008, representing about two hundred trillion British thermal units (200 trillion Btu) of heat energy. Composting can be used for waste treatment and production of fertilizers from those organic materials.

Generally, with current practices of waste composting, heat is generated only as a byproduct of natural composting and is naturally released and not reclaimed. Temperature control is not considered in these systems. The systems **200** described herein provide waste-to-energy and waste treatment systems that can be implemented at the community level to recover heat from composting municipal wastes. The recovered heat can be used for supplying hot water, space heating, and so forth. In embodiments of the disclosure, the systems **200** are implemented for waste treatment, heat recovery, and/or production of fertilizers. Further, in some embodiments the systems **200** are used to recover between approximately fifty percent (50%) and seventy percent (70%) of the heat released by waste stabilization. The systems **200** can provide a sustainable heat output of between approximately ten watts per kilogram (10 W/kg) and fifteen watts per kilogram (15 W/kg) biomass on a wet basis.

A significant amount of heat generated from typical composting processes is discharged to the atmosphere by natural or mechanical ventilation. However, in some instances, about seventy-three percent (73%) of the theoretical energy value of the materials can be recovered. A complex biodegradation process is involved in composting, which reduces the volume and mass of solid organic wastes. Various microorganisms, populations, and mechanisms can be involved in composting different types of wastes.

As described, the system **200** includes the compressor **214**, the expansion valve **212**, the first and second evaporators **208** and **220**, and the first and second condensers **210** and **222**. The first and second evaporators **208** and **220** are used to recover the heat energy from the exhaust air, and from the air space in the tank **202** and the materials of the composting pile, respectively. While one condenser (i.e., the first condenser **210**) is used for direct heat recovery from the exhaust air and the composting pile using heat pump technologies, another condenser (i.e., the second condenser **222**)

can be installed at a higher level to implement a circuit of a heat pipe. In embodiments of the disclosure, high-temperature and high-pressure refrigerant from the compressor **214** is primarily condensed in the first condenser **210** (e.g., for water heating).

In some embodiments, there are three operational modes for the system **200** according to the control strategies as described herein. In a first mode, heat-pump heat-recovery from exhaust air is implemented. In this mode, when the temperature of the composting pile is lower than a set point, the vapor-liquid refrigerant after the expansion valve **212** enters the evaporator **208** installed in the exhaust air duct of the exhaust port **206** to absorb the heat from the exhaust air. In this mode, the energy in the exhaust is recovered by the heat pump system **200**.

In a second, combined heat-pump and heat-pipe mode, when the temperature of the composting pile is above another set point, the second condenser **222** and the second evaporator **220** in the composting pile form a heat-pipe circuit. This circuit is separated from the heat-pump system, and the refrigerant circulates inside the circuit due to different densities of refrigerants in the second evaporator **220** and the second condenser **222**. In this manner, heat is removed from the composting pile to the second condenser **222** for water heating, and the temperature in the composting pile is controlled.

In a third, heat-pump heat-recovery from the exhaust and composting process mode, during the curing and manure stage of composting, the system **200** is operated to recover the heat in the exhaust air and the residual composting materials using the heat pump. In this mode, a portion of the vapor-liquid refrigerant after the expansion valve flows through the second evaporator **220** in the composting pile in order to absorb the heat from the residual compost.

With reference to FIG. 4, a system **200** is operated with yard grass clippings. The system **200** includes four tanks **202** (e.g., reactors), each approximately twenty and five-tenths (20.5) inches in diameter and twenty-seven (27) inches in height, with an effective volume of approximately thirty-two (32) gallons. An air distributor **226** is installed for each reactor to distribute air at least substantially uniformly and supply sufficient oxygen for composting. A heat exchanger **208** (e.g., a water exchanger with copper coils) is positioned inside the fourth reactor to recover the heat generated by biomass degradation and control the temperature of the compost pile. The water is cycled in a circuit comprising a water tank **228** and the coils of the water exchanger by differences in water density. In the system **200**, the second and fourth reactors can also be operated to reuse the spent air of the first and third reactors by controlling valves installed in circulating air ducts. In embodiments of the disclosure, the system **200** also includes one or more temperature and/or humidity sensors **230** and/or a rotameter **232**.

With reference to FIGS. 5 through 7, operational results of the system **200** illustrated in FIG. 4 are described. The total mass of the grass mixture for the four reactors is approximately one hundred six and five-tenths kilograms (106.5 kg), and the compost grass is mixed with approximately twenty-eight and five-tenths percent (28.5%) by weight old compost grass (inoculant) and approximately two and six-tenths percent (2.6%) by weight sawdust. The ratio of carbon-to-nitrogen (C:N) of the mixture is approximately thirty-nine to one (39:1), and the moisture content is approximately eighty percent (80%).

FIG. 5 illustrates the temperatures of inlet and exhaust air of the reactor system **200**. The exhaust air temperature increases linearly at the beginning of the composting; after

ten (10) hours, the temperature reaches fifty-five degrees Celsius (55° C.), and the peak temperature of the exhaust air is about sixty-five degrees Celsius (65° C.). Thus, the system **200** can be used as a heat source for a hot water supply, space heating in a building, and so forth. As illustrated in FIG. 6, during the high-temperature stage of composting, the maximum heat recovered from the grass composting is approximately one thousand nine hundred watts (1,900 W), lasting for approximately two (2) hours, and stable recovered heat of approximately eight hundred watts (800 W) lasts for about twenty (20) hours. FIG. 7 illustrates the recovered energy per kilogram of initial compost mass on a wet basis. The peak recovered energy per kilogram biomass is about twenty-seven watts per kilogram (27 W/kg), and the relative stable value of approximately ten and five-tenths watts per kilogram (10.5 W/kg) lasts for about twenty (20) hours.

The systems **200** described herein provide cost-effective solutions for solid organic waste treatment; effective mitigation of greenhouse gas emissions and reduction of residual containments; and environmental benefits and sustainable development. In 2008, the United States generated about two hundred fifty (250) million tons of trash and recycled and composted about eighty-three (83) million tons of this material, equivalent to about a thirty-three and two-tenths percent (33.2%) recycling rate. On average, one and five-tenths (1.5) pounds of individual waste generation of four and five-tenths (4.5) pounds per person per day was recycled and composted. For a four-member family, annual energy consumption is about 1.11836×10^7 British thermal units (Btu) and 2.87195×10^7 Btu for hot water supply and space heating, respectively. The average waste generation for a typical family is about eighteen (18) pounds per day. About sixty-five percent (65%) of this waste can be composted, and the heat release rate of composting is about ten watts per kilogram (10 W/kg), lasting for about one (1) week. This represents an energy consumption savings of about three thousand, two hundred and fifty-three kilowatt-hours per year (3,253 kWh/year). Further, the residue of composting is an excellent soil amending agent, and it can improve soil fertility and aeration conditions.

The system **100** and/or the system **200**, including some or all of its components, can operate under computer control. For example, a processor can be included with or in a controller configured to control the components and functions of systems **100** and/or systems **200** described herein using software, firmware, hardware (e.g., fixed logic circuitry), manual processing, or a combination thereof. The terms "controller," "functionality," "service," and "logic" as used herein generally represent software, firmware, hardware, or a combination of software, firmware, or hardware in conjunction with controlling the systems **100** and/or the systems **200**. In the case of a software implementation, the module, functionality, or logic represents program code that performs specified tasks when executed on a processor (e.g., central processing unit (CPU) or CPUs). The program code can be stored in one or more computer-readable memory devices (e.g., internal memory and/or one or more tangible media), and so on. The structures, functions, approaches, and techniques described herein can be implemented on a variety of commercial computing platforms having a variety of processors.

A processor provides processing functionality for the system **100** and/or the system **200** and can include any number of processors, micro-controllers, or other processing systems, and resident or external memory for storing data and other information accessed or generated by the system **100** and/or the system **200**. The processor can execute one

or more software programs that implement techniques described herein. The processor is not limited by the materials from which it is formed or the processing mechanisms employed therein and, as such, can be implemented via semiconductor(s) and/or transistors (e.g., using electronic integrated circuit (IC) components), and so forth.

The system **100** and/or the system **200** also includes a memory. The memory is an example of tangible, computer-readable storage medium that provides storage functionality to store various data associated with operation of the system **100** and/or the system **200**, such as software programs and/or code segments, or other data to instruct the processor, and possibly other components of the system **100** and/or the system **200**, to perform the functionality described herein. Thus, the memory can store data, such as a program of instructions for operating the system **100** and/or the system **200** (including its components), and so forth. It should be noted that while a single memory is described, a wide variety of types and combinations of memory (e.g., tangible, non-transitory memory) can be employed. The memory can be integral with the processor, can comprise stand-alone memory, or can be a combination of both. The memory can include, but is not necessarily limited to: removable and non-removable memory components, such as random-access memory (RAM), read-only memory (ROM), flash memory (e.g., a secure digital (SD) memory card, a mini-SD memory card, and/or a micro-SD memory card), magnetic memory, optical memory, universal serial bus (USB) memory devices, hard disk memory, external memory, and so forth. In implementations, the system **100** and/or the system **200** and/or the memory can include removable integrated circuit card (ICC) memory, such as memory provided by a subscriber identity module (SIM) card, a universal subscriber identity module (USIM) card, a universal integrated circuit card (UICC), and so on.

The system **100** and/or the system **200** includes a communications interface. The communications interface is operatively configured to communicate with components of the system **100** and/or the system **200**. For example, the communications interface can be configured to transmit data for storage in the system **100** and/or the system **200**, retrieve data from storage in the system **100** and/or the system **200**, and so forth. The communications interface is also communicatively coupled with the processor to facilitate data transfer between components of the system **100** and/or the system **200** and the processor (e.g., for communicating inputs to the processor received from a device communicatively coupled with the system **100** and/or the system **200**). It should be noted that while the communications interface is described as a component of a system **100** and/or a system **200**, one or more components of the communications interface can be implemented as external components communicatively coupled to the system **100** and/or the system **200** via a wired and/or wireless connection. The system **100** and/or the system **200** can also comprise and/or connect to one or more input/output (I/O) devices (e.g., via the communications interface) including, but not necessarily limited to: a display, a mouse, a touchpad, a keyboard, and so on.

The communications interface and/or the processor can be configured to communicate with a variety of different networks including, but not necessarily limited to: a wide-area cellular telephone network, such as a 3G cellular network, a 4G cellular network, or a global system for mobile communications (GSM) network; a wireless computer communications network, such as a WiFi network (e.g., a wireless local area network (WLAN) operated using IEEE 802.11 network standards); an internet; the Internet; a wide area network (WAN); a local area network (LAN); a personal area network (PAN) (e.g., a wireless personal area network (WPAN) operated using IEEE 802.15 network standards); a public telephone network; an extranet; an intranet; and so on. However, this list is provided by way of example only and is not meant to be restrictive of the present disclosure. Further, the communications interface can be configured to communicate with a single network or multiple networks across different access points.

Although the subject matter has been described in language specific to structural features and/or process operations, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims.

What is claimed is:

1. A system comprising:

- a tank configured to receive biomass feedstock for biodegradation, the tank defining an air space for receiving gas generated during the biodegradation of the biomass feedstock;
- an exhaust port coupled with the tank, the exhaust port configured to exhaust the gas generated during the biodegradation of the biomass feedstock from the air space of the tank;
- a first evaporator disposed in the exhaust port for recovering heat from the exhaust gas;
- a first condenser coupled with the first evaporator;
- an expansion valve coupled between the first evaporator and the first condenser;
- a compressor coupled with the first condenser;
- a coil heat exchanger disposed in the tank for exchanging heat with the biomass feedstock during the biodegradation of the biomass feedstock;
- a second evaporator disposed in the air space defined by the tank, the second evaporator coupled with the heat exchanger for recovering heat from the gas generated during the biodegradation of the biomass feedstock; and
- a second condenser coupled with the second evaporator.

2. The system as recited in claim 1, further comprising a separator for separating gas from liquid, the separator coupled between the compressor and the first evaporator.

3. The system as recited in claim 1, further comprising a mechanical ventilator in fluid communication with the tank, the mechanical ventilator configured to supply air to facilitate the biodegradation of the biomass feedstock.

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