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(71) Applicant: CLEAN ENERGY FUELS CORP. [US/US]; 3020 Old Ranch Parkway, Suite 400, Seal Beach, CA 90740 (US).

(72) Inventor: GRILL, Jeffrey, J.; 1327 Roycroft Avenue, Long Beach, CA 90804 (US).

(74) Agent: HEISEY, David, E.; Sheppard Mullin Richter & Hampton LLP, 12275 El Camino Real, Suite 200, San Diego, CA 92130 (US).

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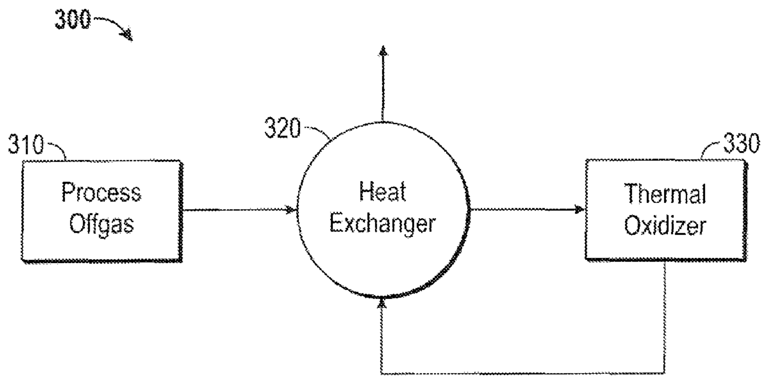

FIG. 3

(57) Abstract: The present invention provides a regenerative thermal oxidizer system, comprising: a recuperative heat exchanger that receives process exhaust gas from an anaerobic digestion process and boosts an inlet temperature of the gas to a second gas temperature; and a regenerative thermal oxidizer thai receives the gas from the heat exchanger, further heats/combusts the gas to a third gas temperature, and feeds the gas back through the recuperative heat exchanger, which recoups heat from the gas such that the gas exits the heat- exchanger at a fourth gas temperature.

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REGENERATIVE THERMAL OXIDIZER FOR THE REDUCTION OR ELIMINATION OF SUPPLEMENTAL FUEL GAS CONSUMPTION

Field of the Invention

The invention broadly relates to biogas applications and, more particularly, to a regenerative thermal oxidizer for the reduction or elimination of supplemental fuel gas consumption.

Background of the Invention

Biogas refers to a gaseous fuel produced by the biological breakdown of organic matter in the absence of oxygen. It is produced by the anaerobic digestion or fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, green waste, plant material and crops. Biogas primarily comprises methane and carbon dioxide, and may contain small amounts of hydrogen sulphide, moisture and siloxanes.

The gases methane, hydrogen and carbon monoxide can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel. Biogas can be used as a fuel for any heating purpose. It can also be produced by anaerobic digesters where it is typically used in a gas engine to convert the chemical energy of the gas into electricity and heat. Anaerobic digestion is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen, also used for industrial or domestic purposes to manage waste and/or to release energy.

The digestion process begins with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers such as carbohydrates and make them available for other bacteria. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. These bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Finally, methanogens convert these products to methane and carbon dioxide.

Anaerobic digesters can use a multitude of feed stocks for the production of methane rich bio-gas including but not limited to purpose-grown energy crops such as maize. Landfills also produce methane rich bio-gas through the anaerobic digestion process. As part of an integrated waste management system, this bio-gas may be collected and processed for beneficial use while simultaneously reducing greenhouse gas emissions into the atmosphere.

Anaerobic digestion is widely used as a source of renewable energy. The process produces a biogas that can be used directly as cooking fuel, in combined heat and power gas engines or upgraded to natural gas quality biomethane. The utilization of biogas as a fuel helps to replace fossil fuels. The nutrient-rich digestate and/or Leachate that is also produced can be used as fertilizer.

The technical expertise required to maintain industrial scale anaerobic digesters coupled with high capital costs and low process efficiencies have limited the level of its industrial application as a waste treatment technology. As a result, it is imperative that anaerobic digesters and landfill gas treatment plants operate at the highest possible efficiency.

Summary of the Invention

The present invention provides a regenerative thermal oxidizer for the reduction or elimination of supplemental fuel gas consumption as well as allowing for the maximization of the product methane recovery.

One embodiment of the invention is directed toward a regenerative thermal oxidizer system, comprising: a recuperative heat exchanger that receives process exhaust gas from an anaerobic digestion process and boosts an inlet gas temperature of the gas to a second gas temperature; and a regenerative thermal oxidizer that receives the gas from the heat exchanger, further heats the gas to the point of auto ignition or combustion to a third gas temperature, and feeds the gas back through the recuperative heat exchanger, which recoups heat from the gas such that the gas exits the heat exchanger at a fourth gas temperature.

In some implementations of the regenerative thermal oxidizer system, the inlet temperature of the gas is about 90 °F, the second gas temperature is about 400 °F, the third gas temperature is about 1200 °F, and the gas exhaust temperature is about 500 °F. Boosting the inlet temperature of the gas to the second gas temperature allows the thermal oxidizer to operate without the use of additional fuel.

Another embodiment of the invention is directed toward a regenerative thermal oxidizer system similar to the above embodiment, but designed to receive process exhaust gas from a landfill gas system.

A further embodiment of the invention is directed toward a method for using a regenerative thermal oxidizer, comprising: receiving at a recuperative heat exchanger process exhaust from an anaerobic digestion process and/or a landfill gas system; boosting an inlet gas temperature of the exhaust gas to a second gas temperature; receiving at a regenerative thermal oxidizer the exhaust from the heat exchanger; further heating the gas to a third gas temperature; feeding the gas back through the recuperative heat exchanger; and recouping heat from the gas such that the gas exits the heat exchanger at a fourth gas temperature.

According to some embodiments of the above method, the inlet temperature of the gas is about 90 °F, the second gas temperature is about 400 °F, the third gas temperature is about 1200 °F, and the gas exhaust temperature is about 500 °F. Boosting the inlet temperature of the gas to the second gas temperature may comprise allowing the thermal oxidizer to operate without the use of additional fuel.

Brief Description of the Drawings

Figure 1 is a flow diagram illustrating the stages of an exemplary anaerobic digestion system.

Figure 2 is a diagram illustrating the stages of an exemplary landfill gas system.

Figure 3 is a diagram illustrating the use of a regenerative thermal oxidizer system in accordance with an embodiment of the invention.

Detailed Description

In the following paragraphs, the present invention will be described in detail by way of example with reference to the attached drawings. Throughout this description, the preferred embodiment and examples shown should be considered as exemplars, rather than as limitations on the present invention. As used herein, the "present invention" refers to any one of the embodiments of the invention described herein, and any equivalents. Furthermore, reference to various feature(s) of the "present invention" throughout this document does not mean that all claimed embodiments or methods must include the referenced feature(s).

Biogas is a renewable energy composed primarily of methane resulting from the natural decomposition of organic waste by anaerobic bacteria. Similar to natural gas, methane captured by a biogas system can be used to provide heat, electrical power or transportation biofuel. Biogas extraction can be used to: (i) produce green and renewable energy; (ii) reduce pollution and greenhouse gases; (iii) reduce waste odors and pathogens; and transform waste into valuable bio-fertilizer.

Fermentation, or anaerobic digestion, is the most common process that breaks down the organic waste. The organic waste may then be oxidized, thereby creating energy. Various types of organic materials include, but are not limited to: (i) biomass, (ii) landfill waste, (iii) sewage, (iv) manure, and (v) plant material. The most common gases produced are methane and carbon dioxide. Other gases that can be formed include hydrogen, nitrogen, and carbon monoxide. Methane, hydrogen, and carbon monoxide can be combusted to create heat and electricity. When biogas is created from existing waste streams, it reduces odors and methane emissions and creates two renewable resources. Methane is a potent greenhouse gas that contributes to global climate change. It is expected that a landfill gas energy project will capture about 60% to 90% of the methane emitted from the landfill, depending on system design and effectiveness.

There are two primary methods of recovering biogas for use as energy, namely: (i) by creating an anaerobic digestion system to process waste, most commonly manure or other wet biomass, and (ii) by recovering natural biogas production formed in existing landfills. Once recovered, biogas can be converted to energy using a number of methods.

Figure 1 is a flow diagram illustrating the stages of an exemplary anaerobic digestion system 100. Specifically, the an anaerobic digestion system 100 comprises a manure collection system 110, a manure handling system 120, an anaerobic digester 130, a biogas handling system 140, gas use devices 150, an effluent storage 160. In addition, at least one flare 170 may be used to burn excess gas. Digester products 180 may be used for bedding, potting soil, land applications, etc. More particularly, manure collection system 110 is used to gather manure and transport it to the anaerobic digester 130. In some cases, existing liquid/slurry manure management systems can be adapted to deliver manure to the anaerobic digester 130. The anaerobic digester 130 may be designed to stabilize manure and optimize the production of methane. A storage facility for digester effluent, or waste matter, is also required.

With further reference to Figure 1, the anaerobic digester 130 outputs biogas into the biogas handling system 140. The biogas may contain approximately 60% methane and 40% carbon dioxide. It is collected, treated, and piped to a gas use device 150. By way of example, the biogas can then be upgraded to natural gas pipeline quality. It may also be used to generate electricity, as a boiler fuel for space or water heating, or for a variety of other uses. At least one flare 170 is also installed to destroy extra gas and as a back-up mechanism for the primary gas use device 160.

The anaerobic digester 130 may be made out of concrete, steel, brick, or plastic. Additionally, the digester 130 includes a tank for pre-mixing the waste and a digester vessel. In some embodiments, the anaerobic digester 130 may comprise a batch digesters or a continuous digester. A batch digester is loaded with organic materials, which are allowed to digest therein. The retention time depends on temperature and other factors. Once the digestion is complete, the effluent is removed and the process is repeated.

In further embodiments, the anaerobic digester 130 may comprise a continuous digester, wherein organic material is constantly or regularly fed into the digester, and wherein the material moves through the digester either mechanically or by the force of the new feed. Unlike batch-type digesters, continuous digesters produce biogas without the interruption of loading material and unloading effluent. Various types of continuous digesters include vertical tank systems, horizontal tank or plug-flow systems, and multiple tank systems.

Anaerobic digestion also occurs naturally underground in landfills, wherein the waste is covered and compressed by the weight of the material that is deposited above. This material prevents oxygen exposure, thereby allowing chemical reactions and microbes to act upon the waste. This encourages an uncontrolled process of biomass decay. The rate of production is affected by waste composition and landfill geometry. Landfill gas may comprise about 40% to 60% methane, and about 40% to 60% carbon dioxide.

Figure 2 is a diagram illustrating the stages of an exemplary landfill gas system 200 including landfill 210, landfill gas wells 220 for active gas collection, landfill gas wellhead 230, landfill gas processing and treatment plant 240, and at least one landfill gas flare 250. Landfill gas is extracted from landfill 210 using a series of wells 220 and a blower/flare system. The landfill gas system 200 directs the collected gas to landfill gas processing and treatment plant 240, where it is processed and treated.

The gas clean-up process creates two streams, namely the product stream and an off spec gas that needs to be destroyed. A thermal oxidizer may be employed to burn this exhaust gas. However, a typical thermal oxidizer is limited by the lower flammability limits of combustion of a gas.

The desired product gas methane recovery of current clean-up technologies is limited by this requirement. Typical volumetric percent values of methane required for combustion in a standard thermal oxidizer range from 8-15% vol. Hence, a system with a higher product methane recovery would not have enough heat/methane content in the exhaust gas to allow for stable combustion unless supplemental fuel was used.

According to embodiments of the invention, a "regenerative thermal oxidizer" preheats the inlet gas with its own hot exhaust gas, thereby bootstrapping the combustion process. This increase in inlet gas temperature to the thermal oxidizer decreases the flammability limit allowing for the destruction of a lower quality methane stream (i.e., allowing for a higher product methane recovery to the product gas stream). Typical ranges of methane required for stable combustion in a regenerative thermal oxidizer can be as low as 0.5% vol., thus allowing for a higher methane recovery to be possible for the gas clean-up system

Figure 3 is a diagram illustrating the use of a regenerative thermal oxidizer system 300 in accordance with an embodiment of the invention. The regenerative thermal oxidizer system 300 is configured to be used as part of an anaerobic digestion system 100 such as disclosed with respect to Figure 1 and a landfill gas system 200 such as disclosed with respect to Figure 2. In particular, process exhaust gas 310 from the anaerobic digestion system 100 or landfill gas system 200 is fed into a recuperative heat exchanger 320, which boosts the inlet temperature and feeds the gas into a regenerative thermal oxidizer 330. This process exhaust gas 310 is excess gas, e.g., from an anaerobic digestion system 100 or a landfill gas system 200, that would normally be destroyed using a flare or standard non-regenerative thermal oxidizer.

With further reference to figure 3, the thermal oxidizer 330 heats the gas such that it exits the thermal oxidizer at a much higher temperature and is fed back through the recuperative heat exchanger 320, which recoups the excess heat and lowers the temperature of the gas. By way of example, the process exhaust gas 310 may be fed into the heat exchanger 320 at a temperature of about 90 °F and is boosted to about 400 °F before entering the regenerative thermal oxidizer 330. In this example, the regenerative thermal oxidizer 330 may raise the gas temperature to about

1200 °F and the heat exchanger then reduces the temperature to about 500 °F. By boosting the gas temperature, the recuperative heat exchanger 320 allows the thermal oxidizer 330 to operate without the use of additional fuel.

It is desirable that plant processes such as anaerobic digestion systems 100 and landfill gas systems 200 operate at the highest efficiency possible. In such processes, this requires very low levels of methane loss in the exhaust gas. However, while a low methane exhaust gas stream is great for plant efficiency, it is not good for the thermal oxidizer. In particular, if the plant is too efficient, a typical thermal oxidizer system may require the addition of supplemental fuel to maintain stable combustion, thereby reducing he overall plant efficiency.

A typical thermal oxidizer requires approximately 10-30% CH_4 to maintain stable combustion. By contrast, the regenerative thermal oxidizer 330 in the embodiment of Figure 3 can operate with as low as 0.5% CH_4, thus allowing for a substantial increase in plant processing efficiency. This is achieved by allowing the incoming reactants to be reheated with the effluent hot gas from the thermal oxidizer exhaust gas stream. Accordingly, the regenerative thermal oxidizer 330 significantly increases plant efficiency by eliminating the penalty associated with conventional thermal oxidizers.

A further embodiment of the invention is directed toward a method for using a regenerative thermal oxidizer, comprising: receiving at a recuperative heat exchanger process exhaust gas from an anaerobic digestion system or a landfill gas system; boosting an inlet temperature of the gas to a second exhaust temperature; receiving at a regenerative thermal oxidizer the gas from the heat exchanger; further heating/combusting the gas to a third exhaust temperature; feeding the gas back through the recuperative heat exchanger; and recouping heat from the gas such that the gas exits the heat exchanger at a fourth gas temperature.

According to some embodiments of the above method, the inlet temperature of the exhaust gas is about 90 °F, the second gas temperature is about 400 °F, the third gas temperature is about 1200 °F, and the fourth gas temperature is about 500 °F. Boosting the inlet temperature of the gas to the second gas temperature may comprise allowing the thermal oxidizer to operate without the use of additional fuel.

One skilled in the art will appreciate that the present invention can be practiced by other than the various embodiments and preferred embodiments, which are presented in this description for purposes of illustration and not of limitation, and the present invention is limited only by the claims that follow. It is noted that equivalents for the particular embodiments discussed in this description may practice the invention as well.

While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example only, and not of limitation. Likewise, the various diagrams may depict an example architectural or other configuration for the invention, which is done to aid in understanding the features and functionality that may be included in the invention. The invention is not restricted to the illustrated example architectures or configurations, but the desired features may be implemented using a variety of alternative architectures and configurations. Indeed, it will be apparent to one of skill in the art how alternative functional, logical or physical partitioning and configurations may be implemented to implement the desired features of the present invention. Also, a multitude of different constituent module names other than those depicted herein may be applied to the various partitions. Additionally, with regard to flow diagrams, operational descriptions and method claims, the order in which the steps are presented herein shall not mandate that various embodiments be implemented to perform the recited functionality in the same order unless the context dictates otherwise.

Although the invention is described above in terms of various exemplary embodiments and implementations, it should be understood that the various features, aspects and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described, but instead may be applied, alone or in various combinations, to one or more of the other embodiments of the invention, whether or not such embodiments are described and whether or not such features are presented as being a part of a described embodiment. Thus the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments.

Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open ended as opposed to limiting. As examples of the foregoing: the term "including" should be read as meaning "including, without limitation" or the like; the term "example" is used to provide exemplary instances of the item in discussion, not an exhaustive or limiting list thereof; the terms "a" or "an" should be read as meaning "at least one," "one or more" or the like; and adjectives such as "conventional," "traditional," "normal," "standard," "known" and terms of similar meaning should not be construed as limiting the item described to a given time period or to an item available as of a given time, but instead should be read to encompass conventional, traditional, normal, or standard technologies that may be available or known now or at any time in the future. Likewise, where this document refers to technologies that would be apparent or known to one of ordinary skill in the art, such technologies encompass those apparent or known to the skilled artisan now or at any time in the future.

A group of items linked with the conjunction "and" should not be read as requiring that each and every one of those items be present in the grouping, but rather should be read as "and/or" unless expressly stated otherwise. Similarly, a group of items linked with the conjunction "or" should not be read as requiring mutual exclusivity among that group, but rather should also be read as "and/or" unless expressly stated otherwise. Furthermore, although items, elements or components of the invention may be described or claimed in the singular, the plural is contemplated to be within the scope thereof unless limitation to the singular is explicitly stated.

The presence of broadening words and phrases such as "one or more," "at least," "but not limited to" or other like phrases in some instances shall not be read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent. The use of the term "module" does not imply that the components or functionality described or claimed as part of the module are all configured in a common package. Indeed, any or all of the various components of a module, whether control logic or other components, may be combined in a single package or separately maintained and may further be distributed across multiple locations.

Additionally, the various embodiments set forth herein are described in terms of exemplary block diagrams, flow charts and other illustrations. As will become apparent to one of ordinary skill in the art after reading this document, the illustrated embodiments and their various alternatives may be implemented without confinement to the illustrated examples. For example, block diagrams and their accompanying description should not be construed as mandating a particular architecture or configuration.

Claims

1. A regenerative thermal oxidizer system, comprising:

a recuperative heat exchanger that receives process exhaust gas from an anaerobic digestion process and boosts an inlet gas temperature of the gas to a second gas temperature; and

a regenerative thermal oxidizer that receives the gas from the heat exchanger, further heats the gas to a third exhaust temperature, and feeds the gas back through the recuperative heat exchanger, which recoups heat from the gas such that the exhaust exits the heat exchanger at a fourth gas temperature.

2. The regenerative thermal oxidizer system of claim 1, wherein the inlet temperature of the gas is about 90 °F.

3. The regenerative thermal oxidizer system of claim 1, wherein the second gas temperature is about 400 °F.

4. The regenerative thermal oxidizer system of claim 1, wherein the third gas temperature is about 1200 °F.

5. The regenerative thermal oxidizer system of claim 1, wherein the fourth gas temperature is about 500 °F.

6. The regenerative thermal oxidizer system of claim 1, wherein boosting the inlet temperature of the gas to the second exhaust temperature allows the thermal oxidizer to operate without the use of additional fuel.

7. A regenerative thermal oxidizer system, comprising:

a recuperative heat exchanger that receives process exhaust gas from a landfill gas system and boosts an inlet temperature of the gas to a second gas temperature; and

a regenerative thermal oxidizer that receives the gas from the heat exchanger, further heats the gas to a third exhaust temperature, and feeds the gas back through the recuperative heat exchanger, which recoups heat from the gas such that the gas exits the heat exchanger at a fourth gas temperature.

8. The regenerative thermal oxidizer system of claim 7, wherein the inlet temperature of the gas is about 90 °F.

9. The regenerative thermal oxidizer system of claim 7, wherein the second gas temperature is about 400 °F.

10. The regenerative thermal oxidizer system of claim 7, wherein the third gas temperature is about 1200 °F.

11. The regenerative thermal oxidizer system of claim 7, wherein the fourth gas temperature is about 500 °F.

12. The regenerative thermal oxidizer system of claim 7, wherein boosting the inlet temperature of the gas to the second gas temperature allows the thermal oxidizer to operate without the use of additional fuel.

13. A method for using a regenerative thermal oxidizer, comprising:

receiving at a recuperative heat exchanger process exhaust gas from an anaerobic digestion process or a landfill gas system;

boosting an inlet temperature of the gas to a second gas temperature;

receiving at a regenerative thermal oxidizer the gas from the heat exchanger;

further heating the gas to a third gas temperature;

feeding the gas back through the recuperative heat exchanger; and

recouping heat from the gas such that the gas exits the heat exchanger at a fourth gas temperature.

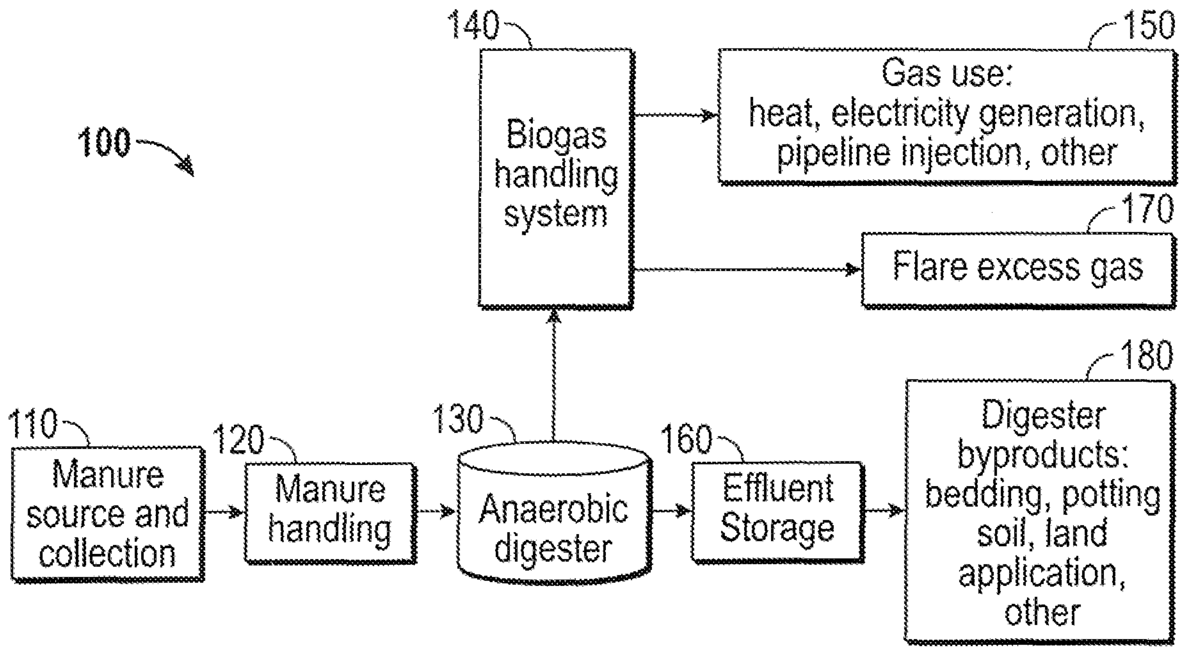
14. The method of claim 13, wherein the inlet temperature of the gas is about 90 °F.

15. The method of claim 13, wherein the second gas temperature is about 400 °F.

16. The method of claim 13, wherein the third gas temperature is about 1200 °F.

17. The method of claim 13, wherein the fourth gas temperature is about 500 °F.

18. The method of claim 13, wherein boosting the inlet temperature of the gas to the second gas temperature comprises allowing the thermal oxidizer to operate without the use of additional fuel.


100
140
Biogas handling system
150
Gas use: heat, electricity generation, pipeline injection, other
170
Flare excess gas
180
110
Manure source and collection
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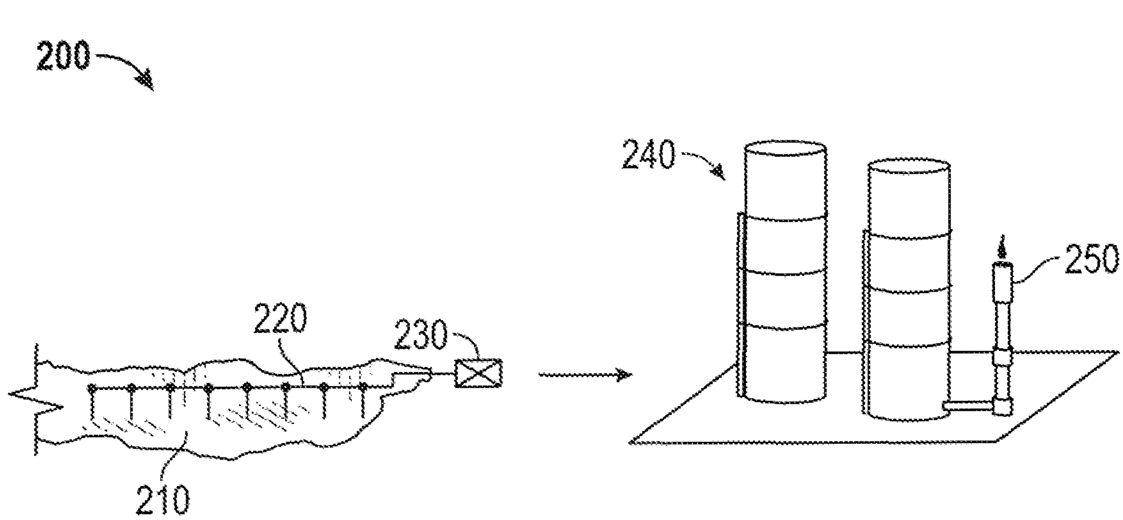
Manure handling
130
Anaerobic digester
160
Effluent Storage
Digester byproducts: bedding, potting soil, land application, other

FIG. 1


200
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250
220
230
210

FIG. 2

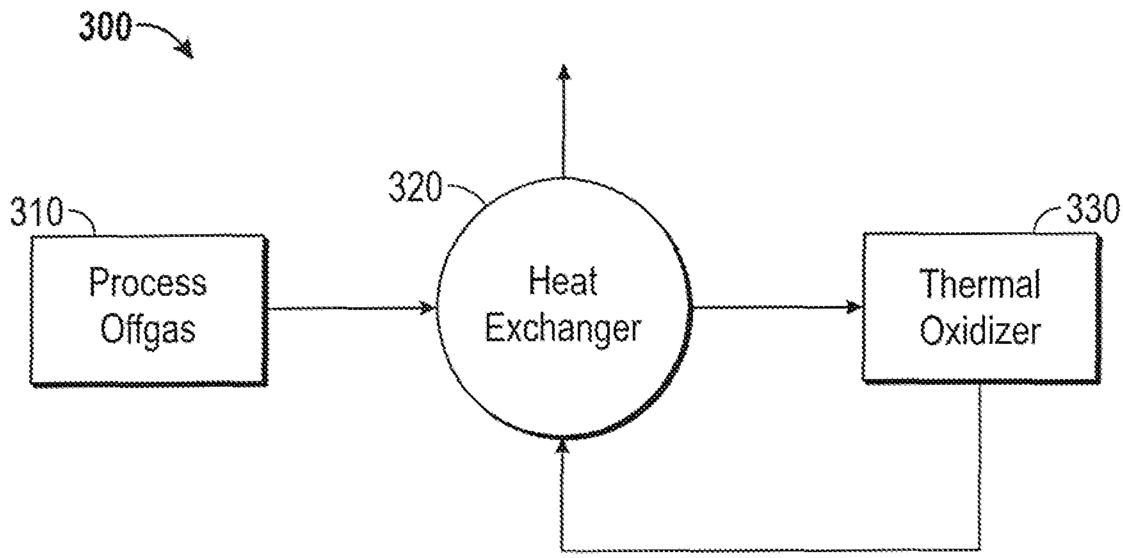
300
310
Process
Offgas
320
Heat
Exchanger
330
Thermal
Oxidizer

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/060882

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F01N 3/10 (2012.01)
USPC - 432/72
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - A61L 9/01; B01D 53/86; C02F 11/02, 11/04; F23G 7/06; F01N 3/10 (2012.01)
USPC - 422/109; 431/5, 170; 432/72; 435/266

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011/0091953 A1 (BOLIN et al) 21 April 2011 (21.04.2011) entire document	1-18
Y	US 2009/0029062 A1 (BAR) 29 January 2009 (29.01.2009) entire document	1-18
Y	WO 99/29413 A1 (HOLST et al) 17 June 1999 (17.06.1999) entire document	7-12
A	US 5,352,115 A (KLOBUCAR) 04 October 1994 (04.10.1994) entire document	1-18

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Date of the actual completion of the international search	Date of mailing of the international search report
26 November 2012	17 DEC 2012

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