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(54) STREAMLINED METHANE GAS GENERATION SYSTEM

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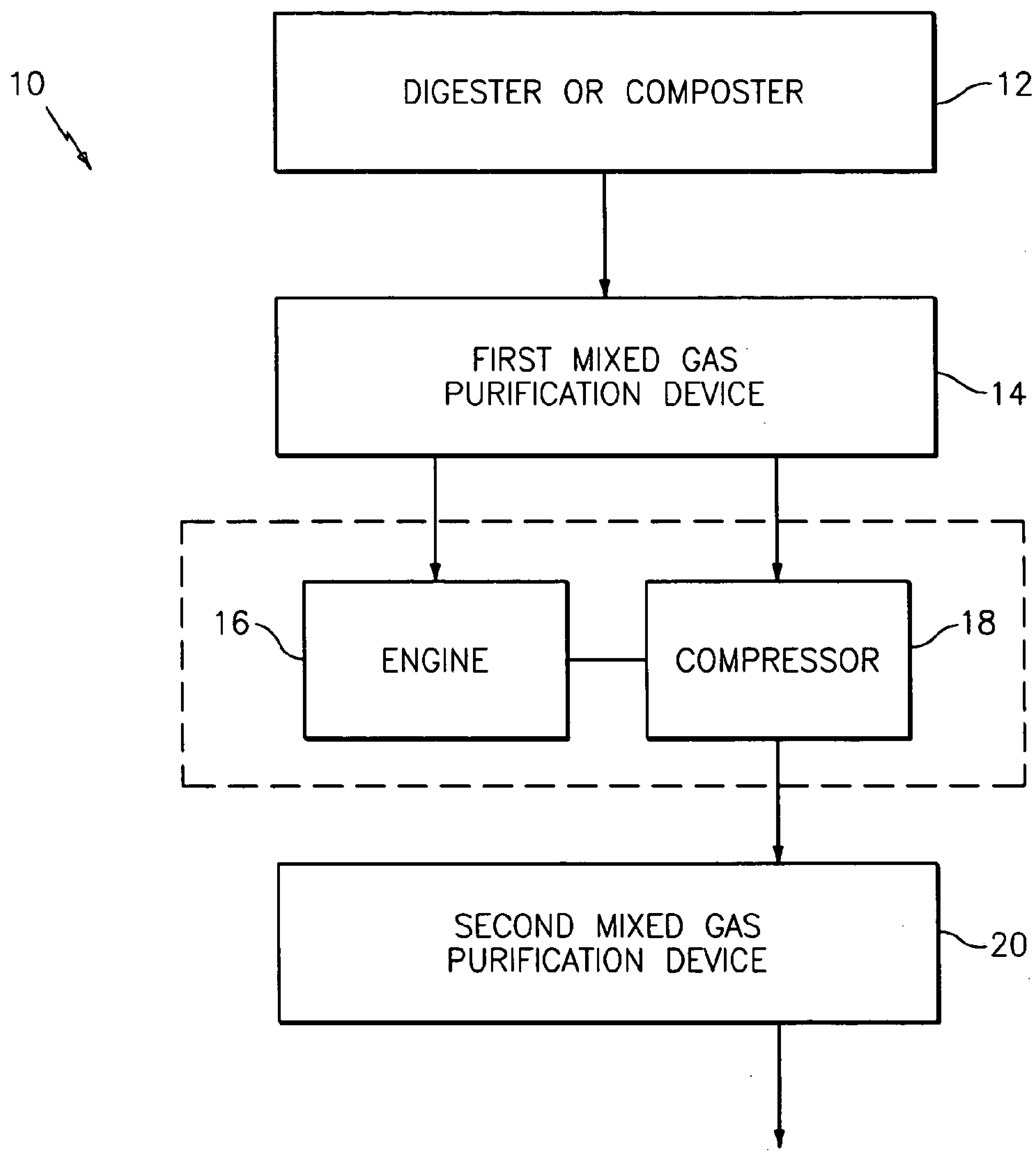
(57) ABSTRACT

A process for producing high purity methane gas from digested or composted organic materials as well as a high purity methane gas generation system that operates in accordance with this process are provided. The inventive system, which is capable of delivering at least about 0.5 slpm of methane product gas, is streamlined in design and provides a more reliable and cost-effective source of renewable methane gas.



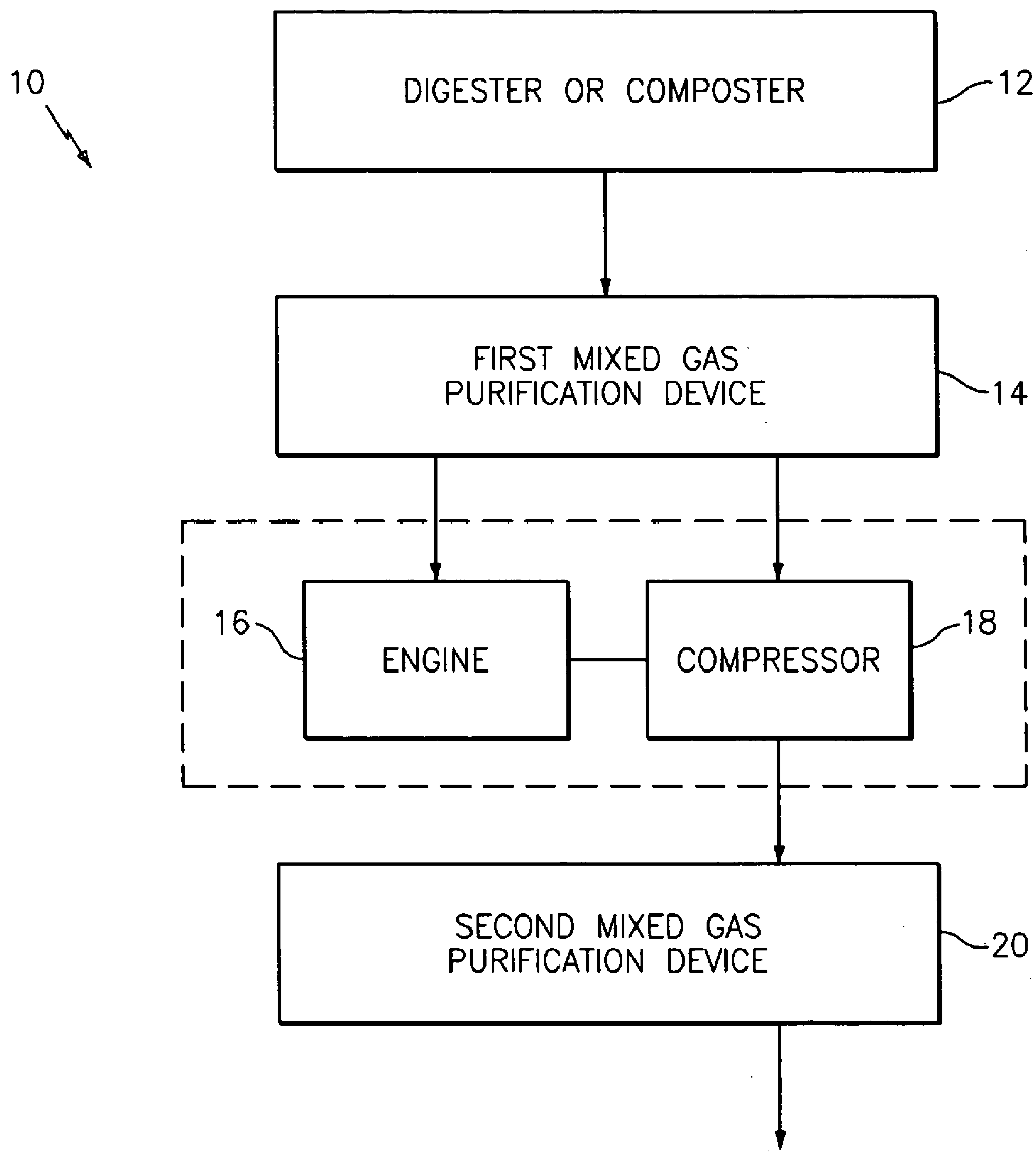
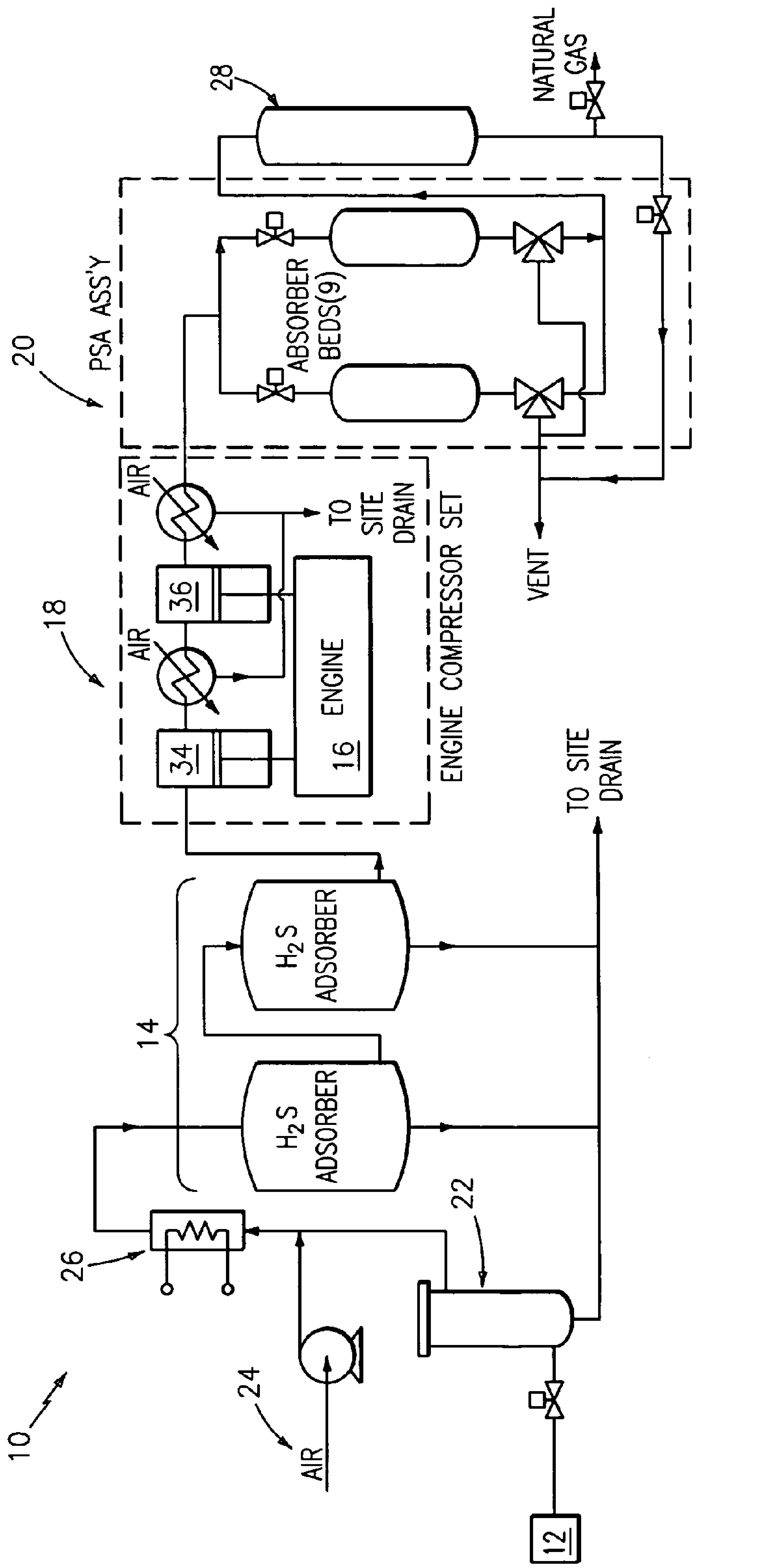

10
DIGESTER OR COMPOSTER
12
FIRST MIXED GAS
PURIFICATION DEVICE
14
16
ENGINE
COMPRESSOR
18
SECOND MIXED GAS
PURIFICATION DEVICE
20

FIG. 1


10
12
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H2S ADSORBER
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18
34
36
16 ENGINE
AIR
AIR
TO SITE DRAIN
ENGINE COMPRESSOR SET
20
PSA ASS'Y
ABSORBER BEDS(9)
VENT
28
NATURAL GAS

FIG. 2

STREAMLINED METHANE GAS GENERATION SYSTEM

RELATED APPLICATION

[0001] This application is a continuation-in-part of U.S. patent application Ser. No. 10/766,552, filed Jan. 27, 2004, which claims priority from U.S. Provisional Patent Application Ser. No. 60/443,410, filed Jan. 29, 2003.

TECHNICAL FIELD OF THE INVENTION

[0002] The present invention generally relates to a process for producing high purity methane gas from biogas or a mixed gas stream and further relates to a streamlined high purity methane gas generation system that operates in accordance with the inventive process.

BACKGROUND ART

[0003] High purity methane gas production by digestion or composting of organic materials offers promise for solving alternative energy problems. For example, in agricultural settings this technology could be used to offset energy expenses, to control odor, and to produce a marketable product.

[0004] Digestion occurs when bacteria produce biogas by decomposing organic matter in the presence of air for aerobic digestion, or in an environment that is devoid of air for anaerobic digestion. Interest in on-farm biogas generation was prompted by the energy crisis of the 1970s, with several farm operations throughout the country experimenting with anaerobic digesters. This experimentation, however, was frequently marked by dissatisfaction on the part of farm owners due to high system cost and/or system failure. The lack of economic feasibility and technological failure appear responsible for the fact that anaerobic digestion has not been widely used in agricultural settings.

[0005] Thus, a need exists for a more reliable and cost effective system for generating renewable sources of high purity methane gas.

[0006] It is therefore an object of the present invention to provide such a system.

[0007] It is a more particular object to provide a high purity methane gas generation system that is streamlined in design and-that reliably and cost-effectively converts organic materials such as animal waste into the desired methane product gas.

[0008] It is another more particular object to provide a reliable, cost-effective and streamlined high purity methane gas generation system that is self-sustaining during normal operation, requiring no outside sources of energy (e.g., electric, gas).

SUMMARY

[0009] The present invention therefore provides a process for producing high purity methane gas from digested or composted organic materials, which comprises:

[0010] 1) digesting or composting organic materials to produce a biogas or mixed gas stream containing methane, carbon dioxide and trace impurities such as hydrogen sulfide, nitrogen and oxygen, wherein the mixed gas stream may also contain small quantities of water;

[0011] 2) directing the biogas or mixed gas stream to a first mixed gas purification device for removing at least a portion of the hydrogen sulfide from the mixed gas stream;

[0012] 3) directing portions of the desulfurized, mixed gas stream to one or more mixed gas-driven engines that power one or more compressors, wherein the mixed gas stream serves to fuel the one or more mixed gas-driven engines;

[0013] 4) directing remaining portions of the desulfurized, mixed gas stream to the one or more compressors for compressing the mixed gas stream; and

[0014] 5) directing the compressed, desulfurized, mixed gas stream to a second mixed gas purification device for removing at least a portion of the carbon dioxide and any excess nitrogen from the mixed gas stream to produce a high purity methane gas product stream.

[0015] The present invention further provides a streamlined, high purity methane gas generation system. The inventive system uses biogas to fuel one or more mixed gas-driven compressors employed therein, and basically comprises:

[0016] 1) one or more devices for digesting and/or composting organic materials to produce a biogas or mixed gas stream containing methane, carbon dioxide and trace impurities such as hydrogen sulfide, nitrogen and oxygen;

[0017] 2) a first mixed gas purification device, which serves to remove at least a portion of the hydrogen sulfide from the mixed gas stream, wherein the first mixed gas purification device is in fluid communication with the one or more devices for digesting and/or composting organic materials;

[0018] 3) at least one mixed gas-driven compressor, which serves to compress or pressurize the desulfurized, mixed gas stream, wherein the at least one mixed gas-driven compressor is in fluid communication with the first mixed gas purification device; and

[0019] 4) a second mixed gas purification device, which serves to remove at least a portion of the carbon dioxide and any excess nitrogen from the compressed, desulfurized, mixed gas stream to produce a high purity methane gas product stream, wherein the second mixed gas purification device is in fluid communication with the at least one mixed gas-driven compressor.

[0020] Other features and advantages of the invention will be apparent to one of ordinary skill from the following detailed description and accompanying drawings.

[0021] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. All publications, patent applications, patents and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Particular features of the disclosed invention are illustrated by reference to the accompanying drawings in which:

[0023] **FIG. 1** is a process flow schematic of a preferred embodiment of the high purity methane gas generation system of the present invention; and

[0024] **FIG. 2** is a process flow schematic of a more preferred embodiment of the high purity methane gas generation system of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

[0025] The methane gas generation system of the present invention is capable of delivering at least one (1) cubic foot per hour at standard conditions (1 scfh) or 0.5 standard liters per minute (0.5 slpm) of the desired methane gas product stream. The inventive system is streamlined in design and provides a more reliable and cost-effective source of renewable methane gas. Further, the inventive system depends upon digested or composted organic materials and not fossil fuels to produce high purity methane gas. Moreover, in a preferred embodiment, the invention system is self-sustaining during normal operation, requiring no outside sources of energy (e.g., electric, natural gas).

[0026] Referring now to **FIG. 1** in detail, a process flow schematic of a preferred embodiment of the high purity methane gas generation system of the present invention is shown and generally designated by reference numeral **10**. In this embodiment, organic materials such as plant material, animal waste, food waste, or human waste, are fed into an anaerobic or aerobic digester or composter **12**. For anaerobic digesters, an anaerobic microbe would be added to digester **12** to form a reaction solution. The digestion period would be allowed to last for from about 3 to about 21 days, while forming a biogas or mixed gas stream containing predominantly methane and carbon dioxide along with trace impurities such as hydrogen sulfide, nitrogen and oxygen. As will be readily apparent to those skilled in the art, the length of the anaerobic digestion period depends upon the type of organic materials being processed and the design of the digester.

[0027] The biogas or mixed gas stream emanating from digester or composter **12** is passed to a first mixed gas purification device **14** for removing at least a portion of the hydrogen sulfide from the stream to maximize the life of, for example, downstream molecular sieves or adsorbents. As is well known to those skilled in the art, hydrogen sulfide may be removed using conventional hydrogen sulfide scrubbers, absorbents or adsorbents such as activated charcoal and bituminous coal, zinc oxide, and mixtures thereof.

[0028] In a preferred embodiment, hydrogen sulfide is removed by catalytic carbon. More specifically, activated bituminous coal is employed in the first mixed gas purification device **14** and a small amount of air is added to the stream prior to entering device **14** so as to facilitate the following reaction on the activated bituminous coal:

$$2H_2S+O_2\rightarrow 2\ H_2O+2S$$

[0029] In a more preferred embodiment, the first mixed gas purification device **14** is a carbon adsorber, which is available from USFilter Westates Carbon, 10 Technology Drive, Lowell, Mass. 01851, under the product designation VENT-SCRUB™ VSC-Series VSC1000 carbon adsorber, preloaded with Midas OCM odor control media.

[0030] A portion of the desulfurized, mixed gas stream is then passed to at least one mixed gas-driven engine **16**, which powers at least one compressor **18**, while remaining portions are passed to the compressor **18**, which compresses the gas to a pressure exceeding the operating pressure of a second mixed gas purification device **20**. In a preferred embodiment, the gas is compressed to a pressure of up to about 1.18 megapascals (MPa), more preferably up to about 1.38 MPa.

[0031] A portion of the mixed gas stream (either before or after hydrogen sulfide removal) may also be passed to one or more mixed gas-driven engines (not shown) for powering one or more generators (also not shown). The generator(s) would produce electric energy for on site use to offset energy expenses and/or for export to electricity grids. One or more batteries may be used in conjunction with the generator(s).

[0032] Upon leaving compressor **18**, the compressed, desulfurized, mixed gas stream is directed to the second mixed gas purification device **20** for removing at least a portion of the carbon dioxide and any excess nitrogen (i.e., nitrogen levels exceeding 0.5% by volume in the mixed gas stream) contained therein.

[0033] The second mixed gas purification device **20** is not limited. In a preferred embodiment, device **20** is a membrane-based separation device or system that employs at least one membrane having carbon dioxide selectivity and optionally, also employs at least one membrane having nitrogen selectivity. In a more preferred embodiment, the second mixed gas purification device **20** is a pressure swing absorption (PSA) device or system comprised of at least two molecular sieve chambers. The PSA device or system may be used alone or in combination with the membrane-based separation device or system.

[0034] Generally speaking, in the contemplated PSA device or system, the mixed gas stream would be passed to at least one of a plurality of adsorption zones at an elevated pressure effective to adsorb carbon dioxide and any excess nitrogen (i.e., the more strongly adsorbed components), while at least methane would pass through (i.e., the less strongly adsorbed component(s)). At a defined time, the passing of the mixed gas stream to the PSA device or system would be terminated and the adsorption zone(s) would be depressurized by one or more concurrent depressurization steps where the pressure would be reduced to a defined level which would permit the separated, less strongly adsorbed methane remaining in the adsorption zone(s) to be drawn off. Then, the adsorption zone(s) would be depressurized by a counter-current depressurization step where the pressure in the adsorption zone(s) would be further reduced by withdrawing desorbed gas counter-currently to the direction of the mixed gas stream. Finally, the adsorption zone(s) would be purged and re-pressurized. As is well known to those skilled in the art, the PSA process is generally carried out in a sequential processing cycle that includes each bed of the PSA device or system.

[0035] In a more preferred embodiment, the PSA device or system **20** is comprised of a housing and at least two molecular sieve chambers (preferably, from about 5 to about 10 molecular sieve chambers) contained within the housing for receiving a molecular sieve or adsorbent for separating carbon dioxide and any excess nitrogen from the mixed gas stream.

[0036] Molecular sieves or adsorbents suitable for use in the present invention are not limited and include carbon fiber composite molecular sieves, zeolite molecular sieves, as well as, other molecularly selective media.

[0037] In yet a more preferred embodiment, the second mixed gas purification device **20** is a rotary valve driven nine bed PSA device or system, which is available from QuestAir Technologies Inc., 6961 Russell Avenue, Burnaby, BC V5J 4R8, under the product designation QuestAir M-3200 PSA gas separator.

[0038] The process for producing high purity methane gas embodied within system **10**, as shown in **FIG. 1**, may be summarized as set forth below:

[0039] 1) digesting or composting organic materials to produce a biogas or mixed gas stream containing methane, carbon dioxide and trace impurities such as hydrogen sulfide, nitrogen and oxygen, wherein the mixed gas stream may also contain small quantities of water;

[0040] 2) directing the biogas or mixed gas stream to a first mixed gas purification device **14** for removing at least a portion of the hydrogen sulfide from the mixed gas stream;

[0041] 3) directing portions of the desulfurized, mixed gas stream to one or more mixed gas-driven engines **16** that power one or more compressors **18**, wherein the mixed gas stream serves to fuel the one or more mixed gas-driven engines **16**;

[0042] 4) directing remaining portions of the desulfurized, mixed gas stream to the one or more compressors **18** for compressing the mixed gas stream; and

[0043] 5) directing the compressed, desulfurized, mixed gas stream to a second mixed gas purification device **20** for removing at least a portion of the carbon dioxide and any excess nitrogen from the mixed gas stream to produce a high purity methane gas product stream.

[0044] The inventive system **10** produces up to about 3000 slpm of methane gas at >90% purity, at pressures ranging from about 1.0 to about 1.4 MPa. The methane gas product stream exiting the second mixed gas purification device **20** meets the Society of Automotive Engineers (SAE) standards for compressed natural gas (CNG) and may be used for low-pressure applications such as fuel for natural gas engines and any other devices that use pipeline natural gas.

[0045] In a more preferred embodiment and as best shown in **FIG. 2**, the methane generation system **10** of the present invention, may further comprise: (1) means **22** for removing at least a portion of any water contained in the mixed gas stream, which is in fluid communication with the digester or composter **12**; (2) means **24** for introducing air into the mixed gas stream to facilitate hydrogen sulfide removal in the first mixed gas purification device **14**, which is in fluid communication with the digester or composter **12**; (3) means **26** for heating the mixed gas stream to prevent water "drop out" and to facilitate hydrogen sulfide removal in the first mixed gas purification device **14**, which is in fluid communication with the digester or composter **12**; (4) optionally, means (not shown) for removing water from the mixed gas stream, which is in fluid communication with the second mixed gas purification device **20**; (5) means **28** for neutralizing sudden pressure surges in the methane gas product stream, which is in fluid communication with the second mixed gas purification device **20**; and (6) optionally, one or more high pressure, mixed-gas driven compressors for further compressing the methane gas product stream for higher-pressure applications (e.g., pressures ranging from about 4.8 to about 25.0 MPa for adding the product stream to natural gas pipelines and/or for fueling CNG vehicles), which is/are in fluid communication with the second mixed gas purification device **20**.

[0046] Means **22** for removing at least a portion of any water contained in the mixed gas stream is not limited and, in a preferred embodiment, comprises a coalescing filter in which small water droplets present in the mixed gas stream combine to form larger droplets that are of sufficient size to accumulate or collect in the filter housing. In a more preferred embodiment, coalescing filter **22** serves to reduce the relative humidity in the mixed gas stream to a level ranging from about 70 to about 95%.

[0047] Means **24** for introducing air into the mixed gas stream to facilitate hydrogen sulfide removal in the first mixed gas purification device **14** is also not limited and, in a preferred embodiment, comprises an air injection system capable of providing air to the mixed gas stream in an amount ranging from about 10 to about 500 times stoichiometric. At low flow conditions (i.e., 20% rated) the air injection system **24** provides no more than about 0.5% by volume, based on the total volume of the mixed gas stream, of air to the mixed gas stream, while at high flow conditions (i.e., 100% rated) system **24** provides an amount of air to the mixed gas stream equal to at least about 10 times the amount of total sulfur in the gas stream.

[0048] Means **26** for heating the mixed gas stream to prevent water "drop out" and to facilitate hydrogen sulfide removal in the first mixed gas purification device **14** is also not limited and, in a preferred embodiment, comprises a heating device capable of heating the mixed gas stream to a temperature ranging from about 15 to about 33° C. before the mixed gas stream enters the first mixed gas purification device **14**.

[0049] Means **28** for neutralizing sudden pressure surges in gas streams is known and includes, but are not limited to, surge tanks capable of holding one to five times the volume of high purity methane gas emanating from the second mixed gas purification device **20**.

[0050] The process for producing high purity methane gas, which is embodied within the more preferred embodiment of device **10**, as shown in **FIG. 2**, may be summarized as set forth below:

[0051] (a) digesting or composting organic materials to produce a mixed gas stream containing methane, carbon dioxide and trace impurities including hydrogen sulfide, nitrogen and oxygen, wherein the mixed gas stream may also contain small quantities of water;

[0052] (b) directing the mixed gas stream to: (i) means **22** for removing at least a portion of any water contained in the mixed gas stream; (ii) means **24** for aerating the mixed gas stream; and (iii) means **26** for heating the mixed gas stream to a temperature ranging from about 15 to about 33° C.;

[0053] (c) directing the condensed, aerated and heated mixed gas stream to a first mixed gas purification device **14** for removing at least a portion of the hydrogen sulfide contained therein;

[0054] (d) directing a portion of the desulfurized, mixed gas stream to a mixed gas-driven engine **16** for fueling same, wherein the mixed gas-driven engine **16** powers two compressors **34**, **36**;

[0055] (e) directing remaining portions of the desulfurized, mixed gas stream to the compressors **34**, **36** for compressing the mixed gas stream to a pressure of up to about 1.38 MPa;

[0056] (f) directing the compressed, desulfurized, mixed gas stream to a second mixed gas purification device **20** for removing at least a portion of the carbon dioxide and any excess nitrogen contained therein to produce a high purity methane gas product stream; and

[0057] (g) directing the high purity methane gas product stream to means **28** for neutralizing sudden pressure surges in the product stream.

[0058] The more preferred embodiment of inventive system **10** produces from about 200 to about 1000 slpm of methane gas at >98.5% purity, at a pressure of about 1.4 MPa.

[0059] Although this invention has been shown and described with respect to detailed embodiments thereof, it will be apparent to those skilled in the art that various changes in form and detail thereof may be made without departing from the spirit and scope of the invention.

1. A streamlined process for producing high purity methane gas from digested or composted organic materials, which comprises:

(a) digesting or composting organic materials to produce a mixed gas stream containing methane, carbon dioxide and trace impurities including hydrogen sulfide, nitrogen and oxygen, wherein the mixed gas stream may also contain small quantities of water;

(b) directing the biogas or mixed gas stream to a first mixed gas purification device for removing at least a portion of the hydrogen sulfide from the mixed gas stream;

(c) directing portions of the desulfurized, mixed gas stream to one or more mixed gas-driven engines that power one or more compressors, wherein the mixed gas stream serves to fuel the one or more mixed gas-driven engines;

(d) directing remaining portions of the desulfurized, mixed gas stream to the one or more compressors for compressing the mixed gas stream; and

(e) directing the compressed, desulfurized, mixed gas stream to a second mixed gas purification device for removing at least a portion of the carbon dioxide and any excess nitrogen from the mixed gas stream to produce a high purity methane gas product stream.

2. The streamlined process for producing high purity methane gas of claim 1, wherein the biogas or mixed gas stream is produced by anaerobically digesting the organic materials.

3. The streamlined process for producing high purity methane gas of claim 1, which further comprises directing portions of the mixed gas stream or desulfurized, mixed gas stream to one or more mixed gas-driven engines for powering one or more generators.

4. A streamlined process for producing high purity methane gas from digested or composted organic materials, which comprises:

(a) digesting or composting organic materials to produce a mixed gas stream containing methane, carbon dioxide and trace impurities including hydrogen sulfide, nitrogen and oxygen, wherein the mixed gas stream may also contain small quantities of water;

(b) directing the mixed gas stream to means for: (i) removing at least a portion of any water contained in the mixed gas stream; (ii) aerating the mixed gas stream; and (iii) heating the mixed gas stream to a temperature ranging from about 15 to about 33° C.;

(c) directing the condensed, aerated and heated mixed gas stream to a first mixed gas purification device for removing at least a portion of the hydrogen sulfide contained therein;

(d) directing a portion of the desulfurized, mixed gas stream to one or more mixed gas-driven engines for fueling same, wherein the one or more mixed gas-driven engines power one or more compressors;

(e) directing remaining portions of the desulfurized, mixed gas stream to the one or more compressors for compressing the mixed gas stream; and

(f) directing the compressed, desulfurized, mixed gas stream to a second mixed gas purification device for removing at least a portion of the carbon dioxide and any excess nitrogen contained therein to produce a high purity methane gas product stream.

5. The streamlined process for producing high purity methane gas of claim 4, wherein the mixed gas stream is produced by anaerobically digesting the organic materials.

6. The streamlined process for producing high purity methane gas of claim 4, which further comprises directing portions of the mixed gas stream or desulfurized, mixed gas stream to one or more mixed gas-driven engines for powering one or more generators.

7. The streamlined process for producing high purity methane gas of claim 4, which further comprises directing the high purity methane gas product stream to means for neutralizing sudden pressure surges in the product stream.

8. A streamlined, high purity methane gas generation system, which comprises:

(a) one or more devices for digesting and/or composting organic materials to produce a mixed gas stream containing methane, carbon dioxide and trace impurities including hydrogen sulfide, nitrogen and oxygen;

(b) a first mixed gas purification device, which serves to remove at least a portion of the hydrogen sulfide from the mixed gas stream, wherein the first mixed gas purification device is in fluid communication with the one or more devices for digesting and/or composting organic materials;

(c) at least one mixed gas-driven compressor, which serves to compress the desulfurized, mixed gas stream, wherein the at least one mixed gas-driven compressor is in fluid communication with the first mixed gas purification device; and

(d) a second mixed gas purification device, which serves to remove at least a portion of the carbon dioxide and any excess nitrogen from the compressed, desulfurized, mixed gas stream to produce a high purity methane gas product stream, wherein the second mixed gas purification device is in fluid communication with the at least one mixed gas-driven compressor.

9. The streamlined, high purity methane gas generation system of claim 8, wherein the system is self-sustaining during operation, requiring no outside sources of energy.

10. The streamlined, high purity methane gas generation system of claim 8, wherein the one or more devices for digesting and/or composting organic materials comprises one or more anaerobic digesters.

11. The streamlined, high purity methane gas generation system of claim 8, which further comprises one or more generators which are powered by one or more mixed gas-driven engines.

12. The streamlined, high purity methane gas generation system of claim 8, wherein the second mixed gas purification device is a pressure swing absorption device.

13. The streamlined, high purity methane gas generation system of claim 12, wherein the pressure swing absorption device comprises at least two molecular sieve chambers.

14. The streamlined, high purity methane gas generation system of claim 8, which further comprises one or more high pressure, mixed gas-driven compressors for further compressing the methane gas product stream, wherein the one or more high pressure, mixed gas-driven compressors are in fluid communication with the second mixed gas purification device.

15. The streamlined, high purity methane gas generation system of claim 8, which produces up to 3,000 standard liters per minute of methane gas at pressures ranging from about 1.0 to about 1.4 megapascals, wherein the methane gas has a purity level of greater than 90%.

16. A streamlined, high purity methane gas generation system, which comprises:

(a) one or more devices for digesting and/or composting organic materials to produce a mixed gas stream containing methane, carbon dioxide and trace impurities including hydrogen sulfide, nitrogen and oxygen;

(b) means for removing at least a portion of any water contained in the mixed gas stream, which is in fluid communication with the one or more devices for digesting and/or composting organic materials;

(c) means for aerating the mixed gas stream, which is in fluid communication with the one or more devices for digesting and/or composting organic materials;

(d) means for heating the mixed gas stream to a temperature ranging from about 15 to about 33° C., which is in fluid communication with the one or more devices for digesting and/or composting organic materials;

(e) a first mixed gas purification device, which serves to remove at least a portion of the hydrogen sulfide from the mixed gas stream, wherein the first mixed gas purification device is in fluid communication with the one or more devices for digesting and/or composting organic materials;

(f) at least one mixed gas-driven compressor in fluid communication with the first mixed gas purification device; and

(g) a second mixed gas purification device, which serves to remove at least a portion of the carbon dioxide and any excess nitrogen from the mixed gas stream to produce a methane gas product stream, wherein the second mixed gas purification device is in fluid communication with the at least one mixed-gas driven compressor.

17. The streamlined, high purity methane gas generation system of claim 16, wherein the system is self-sustaining during operation, requiring no outside sources of energy.

18. The streamlined, high purity methane gas generation system of claim 16, wherein the one or more devices for digesting and/or composting organic materials comprises one or more anaerobic digesters.

19. The streamlined, high purity methane gas generation system of claim 16, which further comprises one or more generators which are powered by one or more mixed gas-driven engines.

20. The streamlined, high purity methane gas generation system of claim 16, wherein the second mixed gas purification device is a pressure swing absorption device.

21. The streamlined, high purity methane gas generation system of claim 20, wherein the pressure swing absorption device comprises at least two molecular sieve chambers.

22. The streamlined, high purity methane gas generation system of claim 16, which further comprises one or more high pressure, mixed-gas driven compressors for further compressing the methane gas product stream, wherein the one or more high pressure, mixed gas-driven compressors are in fluid communication with the second mixed gas purification device.

23. The streamlined, high purity methane gas generation system of claim 16, which produces up to 3,000 standard liters per minute of methane gas at pressures ranging from about 1.0 to about 1.4 megapascals, wherein the methane gas has a purity level of greater than 90%.

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