CLAIMS

1. A method comprising:

(a) generating a first gas stream comprising at least 4% ozone by weight and at least 50% oxygen by weight;

(b) separating at least a portion of the ozone from the first gas stream;

(c) forming a second gas stream comprising at least a portion of the ozone that was separated from the first gas stream in step (b), the second gas stream having no more than 18% oxygen by weight;

(d) treating wastewater using an anaerobic digestion process; and

(e) contacting the second gas stream with at least a portion of the wastewater either before the wastewater is treated using the anaerobic digestion process or while the wastewater is treated using the anaerobic digestion process.

2. The method of claim 1, wherein steps (b) and (c) comprise steps of a pressure swing adsorption cycle.

3. The method of claim 1, wherein step (c) comprises forming a second gas stream comprising a sweep gas and at least a portion of the ozone that was separated from the first gas stream in step (b), the second gas stream having no more than 18% oxygen by weight and the sweep gas comprising at least 90% nitrogen by volume.

4. The method of claim 1, wherein step (c) comprises forming a second gas stream comprising a sweep gas and at least a portion of the ozone that was separated from the first gas stream in step (b), the second gas stream having no more than 18% oxygen by weight and the sweep gas consisting essentially of a mixture of carbon dioxide and nitrogen.

5. The method of claim 1, further comprising:

(f) separating a third gas stream from the first gas stream, the third gas stream comprising at least 80% oxygen; and

(g) delivering the third gas stream to an aerobic digester.

6. The method of claim 1, further comprising:

(f) separating a third gas stream from the first gas stream, the third gas stream comprising at least 80% oxygen; and

(g) using the third gas stream as at least a portion of a supply gas stream for an ozone generator used to perform step (a).

7. The method of claim 1, wherein the performance of step (e) begins in a digester pretreatment chamber located upstream from and in fluid flow communication with an anaerobic digester in which step (d) is performed.

8. The method of claim 1, further comprising:

(f) enabling a gas-phase effluent to flow from an anaerobic digester to a biogas separator;

(g) separating carbon dioxide contained in the gas-phase effluent from biogas; and

(h) reusing in step (c) the carbon dioxide separated during step (k).

9. The method of claim 3, further comprising:

(f) cooling at least a portion of biogas from an anaerobic digester using liquid nitrogen, which results in at least some of the liquid nitrogen becoming nitrogen vapor; and

(g) using the nitrogen vapor as at least a portion of the sweep gas.

10. A method for treating wastewater with ozone, the method comprising:

(a) generating a first gas stream comprising at least 4% ozone by weight and at least 50% oxygen by weight;

(b) transferring at least a portion of the ozone from the first gas stream to a second gas stream using a pressure swing adsorption cycle, the second gas stream comprising no more than 18% oxygen by weight; and

(c) bringing the second gas stream into contact with the wastewater either upstream from an anaerobic digester or within an anaerobic digester.

11. The method of claim 10, wherein step (c) at least partially occurs in a digester pretreatment chamber that is in fluid flow communication with the anaerobic digester and

the pressure swing adsorption cycle, the digester pretreatment chamber being downstream from the pressure swing adsorption cycle.

12. The method of claim 10, further comprising:

(d) enabling a gas-phase effluent stream to flow from the anaerobic digester to a biogas separator;

(e) separating the biogas into a first component stream comprising carbon dioxide and a second component stream comprising methane; and

(f) reusing the first component stream as the second gas stream of step (b).

13. The method of claim 10, further comprising:

(d) enabling a gas-phase effluent stream to flow from the anaerobic digester to a biogas separator;

(e) separating the biogas into a first component stream comprising carbon dioxide and a second component stream comprising methane;

(f) cooling the second component stream using liquid nitrogen, which results in at least some of the liquid nitrogen becoming nitrogen vapor; and

(g) using at least one of the first component stream and the nitrogen vapor as the second gas stream of step (b).

14. A system for treating wastewater with ozone, the system comprising:

an ozone generator that is operationally configured to generate a first gas stream from a source of oxygen, the first gas stream comprising at least 4% ozone by weight and at least 50% oxygen by weight;

a pressure swing adsorption system that is operationally configured to receive the first gas stream and to transfer at least a portion of the ozone from the first gas stream to a second gas stream, to discharge the second gas stream, and to discharge a third gas stream, the second gas stream comprising no more than 18% oxygen by weight, the third gas stream comprising gas remaining from the first gas stream after the at least a portion of the ozone is transferred to the second gas stream, the third gas stream comprising at least 50% oxygen by weight; and

a first interface that is operationally configured to bring the second gas stream into contact with wastewater either within an anaerobic digester or within a first vessel that is in fluid flow communication with an anaerobic digester.

15. The system of claim 14, wherein the pressure swing adsorption system comprises a sieve, the pressure swing adsorption system being operationally configured to adsorb the at least a portion of the ozone onto the sieve, then to desorb at least a portion of the adsorbed ozone using a sweep gas, the second gas stream comprising the desorbed ozone and the sweep gas.

16. The system of claim 15, wherein the sweep gas comprises at least 90% nitrogen by volume.

17. The system of claim 14, further comprising an aerobic digester and a second interface that is operationally configured to bring the third gas stream into contact with the wastewater either within the aerobic digester or within a second vessel that is in fluid flow communication with the aerobic digester.

18. The system of claim 14, further comprising an output line in fluid flow communication with the pressure swing adsorption system and the ozone generator, the output line being operationally configured to return the third gas stream to the ozone generator.

19. The system of claim 15, further comprising a biogas separator in fluid flow communication with the anaerobic digester, the biogas separator being operationally configured to separate the biogas into a first component stream comprising carbon dioxide and a second component stream comprising methane, and wherein the sweep gas comprises the first component stream.

20. The system of claim 19, further comprising a heat exchanger that is operationally configured to cool the second component stream using liquid nitrogen and a third vessel that is operationally configured to receive nitrogen vapor from the heat exchanger, wherein the sweep gas comprises the nitrogen vapor.

CLAIMS

1. A method for treating wastewater with ozone and with anaerobic and aerobic digestion processes, the method comprising:
    (a) introducing a stream comprising oxygen into an ozone generator and converting a portion of the oxygen to ozone thereby generating a first gas stream comprising at least 4% ozone by weight and at least 50% oxygen by weight;
    (b) separating at least a portion of the ozone from the first gas stream;
    (c) forming a second gas stream comprising at least a portion of the ozone that was separated from the first gas stream in step (b), the second gas stream having no more than 18% oxygen by weight;
    (d) treating wastewater using an anaerobic digestion process;
    (e) contacting the second gas stream with at least a portion of the wastewater either before the wastewater is treated using the anaerobic digestion process and/or while the wastewater is treated using the anaerobic digestion process;
    (f) separating a third gas stream from the first gas stream, the third gas stream comprising at least 50% oxygen; and
    (g) delivering the third gas stream or a portion thereof to an aerobic digester used to treat the wastewater;

    wherein steps (b), (c) and (f) comprise steps of a pressure swing adsorption cycle.

2. The method of claim 1, wherein step (c) comprises forming a second gas stream comprising a sweep gas and at least a portion of the ozone that was separated from the first gas stream in step (b), the second gas stream having no more than 18% oxygen by weight.

3. The method of claim 2, wherein the sweep gas comprises at least 90% nitrogen by volume and/or consists essentially of a mixture of carbon dioxide and nitrogen.

4. The method of claim 2 or 3, further comprising the steps of:
    enabling a gas-phase effluent to flow from an anaerobic digester to a biogas separator;
    separating carbon dioxide contained in the gas-phase effluent from biogas; and
    reusing the carbon dioxide as at least a portion of the sweep gas.

5. The method of any one of claims 2 to 4, further comprising the steps of:
    cooling at least a portion of biogas from an anaerobic digester using liquid nitrogen, which results in at least some of the liquid nitrogen becoming nitrogen vapor; and

using the nitrogen vapor as at least a portion of the sweep gas.

6. The method of any preceding claim, wherein the third gas stream comprises at least 80% oxygen.

7. The method of claim 6, wherein step (g) comprises:
delivering a portion of the third gas stream to an aerobic digester used to treat the wastewater; and
using a portion of the third gas stream as at least a portion of a supply gas stream for the ozone generator used to perform step (a).

8. The method of any preceding claim, wherein the performance of step (e) begins in a digester pretreatment chamber located upstream from and in fluid flow communication with an anaerobic digester in which step (d) is performed.

9. A system for treating wastewater with ozone and with anaerobic and aerobic digestion processes, the system comprising:
an ozone generator that is operationally configured to generate a first gas stream from a source of oxygen, the first gas stream comprising at least 4% ozone by weight and at least 50% oxygen by weight;
a pressure swing adsorption system that is operationally configured to receive the first gas stream and to transfer at least a portion of the ozone from the first gas stream to a second gas stream, to discharge the second gas stream, and to discharge a third gas stream, the second gas stream comprising no more than 18% oxygen by weight, the third gas stream comprising gas remaining from the first gas stream after the at least a portion of the ozone is transferred to the second gas stream, the third gas stream comprising at least 50% oxygen by weight;
an anaerobic digester;
a first interface that is operationally configured to bring the second gas stream into contact with wastewater either within the anaerobic digester and/or within a first vessel that is in fluid flow communication with the anaerobic digester;
an aerobic digester; and
a second interface that is operationally configured to bring the third gas stream or a portion thereof into contact with the wastewater either within the aerobic digester or within a second vessel that is in fluid flow communication with the aerobic digester.

10. The system of claim 9, wherein the pressure swing adsorption system comprises a sieve, the pressure swing adsorption system being operationally configured to adsorb the at least a portion of the ozone onto the sieve, then to desorb at least a portion of the adsorbed ozone using a sweep gas, the second gas stream comprising the desorbed ozone and the sweep gas.

11. The system of claim 10, further comprising a biogas separator in fluid flow communication with the anaerobic digester, the biogas separator being operationally configured to separate a biogas from the anaerobic digester into a first component stream comprising carbon dioxide and a second component stream comprising methane, and wherein the sweep gas comprises the first component stream.

12. The system of claim 11, further comprising a heat exchanger that is operationally configured to cool the second component stream using liquid nitrogen and a third vessel that is operationally configured to receive nitrogen vapor from the heat exchanger, wherein the sweep gas comprises the nitrogen vapor.

13. The system of any one of claims 9 to 12, further comprising an output line in fluid flow communication with the pressure swing adsorption system and the ozone generator, the output line being operationally configured to return a portion of the third gas stream to the ozone generator.