CLAIMS

What is claimed:

1. A method for monitoring one or more silicon-containing compounds present in a biogas, the method comprising:

providing a non-absorptive gas to a sample cell, the non-absorptive gas having substantially no infrared absorptions in a specified wavelength range of interest;

obtaining a first spectral measurement from the sample cell;

providing a biogas to the sample cell;

obtaining a second spectral measurement from the sample cell;

generating a first absorption spectrum based on a ratio of the first spectral measurement and the second spectral measurement;

generating at least one surrogate absorption spectrum based on, at least, individual absorption spectrum for each of a subset of one or more silicon-containing compounds selected from a larger set of known silicon-containing compounds with known concentrations; and

calculating a total concentration of the one or more silicon-containing compounds in the biogas based on the first absorption spectrum and the at least one surrogate absorption spectrum.

2. The method of claim 1, wherein the one or more silicon-containing compounds in the biogas include at least one siloxane.

3. The method of claim 1, wherein the larger set of known silicon-containing compounds includes at least one siloxane.

4. The method of claim 1, wherein the subset of one or more silicon-containing compounds includes at least one siloxane.

5. The method of claim 1, wherein the total concentration comprises one of a total concentration of siloxane compounds in the biogas, a total concentration of other silicon-

containing compounds in the biogas or a total concentration of all silicon-containing compounds in the biogas.

6. The method of claim 1, further comprising applying a correction factor to the total concentration, wherein the correction factor scales the total concentration by a factor.

7. The method of claim 1, further comprising selecting the subset of one or more silicon-containing compounds based on spectral matching of the known silicon-containing compounds with the one or more silicon-containing compounds present in the biogas.

8. The method of claim 1, wherein the larger set of known silicon-containing compounds comprises D3-siloxane, D4-siloxane, D5-siloxane, D6-siloxane, L2-siloxane, L3-siloxane, L4-siloxane and L5-siloxane.

9. The method of claim 1, wherein the subset of one or more silicon-containing compounds comprises 3 to 5 siloxane compounds selected from the larger set of known silicon-containing compounds and the silicon-containing component of trimethyl silanol (TMS).

10. The method of claim 1, wherein the biogas comprises a landfill gas.

11. The method of claim 10, wherein the subset of one or more silicon-containing compounds comprises one of a) L2-siloxane, L3-siloxane and D4-siloxane; b) L2-siloxane, D3-siloxane and D4-siloxane; or c) L2-siloxane, D3-siloxane and D5 siloxane.

12. The method of claim 11, wherein the subset of one or more silicon-containing compounds further comprises the silicon-containing component of trimethyl silanol (TMS).

13. The method of claim 1, wherein the biogas comprises a digester biogas.

14. The method of claim 13, wherein the subset of one or more silicon-containing compounds comprises one of a) D3-siloxane, D5-siloxane and L3-siloxane; b) D4-siloxane, D5-siloxane and L3-siloxane; or c) D3-siloxane, D5-siloxane and L2-siloxane.

15. The method of claim 1, wherein the at least one surrogate absorption spectrum further comprises individual absorption spectrum for each of a subset of one or more hydrocarbon compounds selected from a larger set of known hydrocarbon compounds with known concentrations.

16. The method of claim 15, wherein the biogas comprises a digester gas and the larger set of known hydrocarbon compounds comprises ethane, propane and butane.

17. The method of claim 15, wherein the biogas comprises a landfill gas and the larger set of known hydrocarbon compounds comprises toluene, methanol and Ethanol.

18. The method of claim 15, wherein the at least one surrogate absorption spectrum is a model based on, at least, the individual absorption spectrum for each of the subset of one or more silicon-containing compounds and the individual absorption spectrum for each of the subset of one or more hydrocarbon compounds.

19. The method of claim 1, wherein at least one of the subset of one or more silicon-containing compounds is present in the biogas.

20. The method of claim 1, wherein at least one of the subset of one or more silicon-containing compounds is absent from the biogas.

21. The method of claim 1, wherein calculating comprises performing, using a processor, multiple regression analysis using the first absorption spectrum and the at least one surrogate absorption spectrum.

22. The method of claim 21, further comprising performing the multiple regression analysis using classical Least Square (CLS), Partial Least Squares (PLS), Inverse Least Squares (ILS), or Principal Component Analysis (PCA).

23. The method of claim 1, further comprising calculating, using a processor, the total concentration of the one or more silicon-containing compounds in the biogas in real-time and in-situ.

24. The method of claim 1, further comprising taking the second spectral measurement over an acquisition period of about 10 seconds to about 20 seconds.

25. The method of claim 1, further comprising determining a value for the total concentration of the one or more silicon-containing compounds such that the at least one surrogate absorption spectrum is substantially similar to the first absorption spectrum.

26. The method of claim 1, further comprising providing the biogas from animal waste, wastewater or a landfill.

27. The method of claim 1, wherein the total concentration is computed by representing spectral features of the one or more silicon-containing compounds in the biogas using a classical least square (CLS) fitting routine based on the first absorption spectrum, the at least one surrogate absorption spectrum and at least one of a baseline value or an offset value.

28. A system for monitoring one or more silicon-containing compounds in a biogas, the system comprising:

a source of a first beam of radiation;

an interferometer receiving the first beam of radiation from the source and forming a second beam of radiation comprising an interference signal;

a sample cell in optical communication with the interferometer;

a flow mechanism establishing a first flow of a non-absorptive gas having substantially no infrared absorptions in a specified wavelength range of interest and a second flow of the biogas through the sample cell;

a cooled detector in optical communication with the sample cell, the cooled detector receiving:

a first interference signal propagating through the non-absorptive gas in the sample cell; and

a second interference signal propagating through a sample gas in the sample cell, the sample gas comprising the biogas;

a processor in electrical communication with the cooled detector, the processor configured to calculate a total concentration of the one or more silicon-containing compounds in the biogas based on:

a first absorption spectrum based on a ratio of the first interference signal and the second interference signal;

a set of surrogate absorption spectra based on, at least, individual absorption spectrum for each of a subset of one or more silicon-containing compounds selected from a larger set of known silicon-containing compounds with known concentrations; and

a housing in which the source, the interferometer, the sample cell, the cooled detector and the processor are disposed.

29. The system of claim 28, wherein the one or more silicon-containing compounds in the biogas comprises at least one siloxane.

30. The system of claim 28, wherein the sample cell comprises:

a concave reflective field surface at a first end of the sample cell; and

a substantially spherical, concave reflective objective surface at a second end of the sample cell in a confronting relationship to the field surface, the objective surface having a cylindrical component increasing coincidence of foci in at least one plane to maximize throughput of the second beam of radiation propagating through the sample cell via multiple reflections on each of the field surface and the objective surface.

31. The system of claim 28, wherein the set of surrogate absorption spectra is a model based on, at least, the individual absorption spectrum for each of the subset of one or more silicon-containing compounds and individual absorption spectrum for each of a subset of one or more hydrocarbon compounds selected from a larger set of known hydrocarbon compounds with known concentrations.

32. A computer readable product, tangibly embodied on a non-transitory information carrier or a machine readable storage device, and operable on a digital signal processor for a biogas

detection system, the computer readable product including instructions operable to cause the digital signal processor to:

receive a first spectral measurement of a non-absorptive gas in a sample cell, the non-absorptive gas having substantially no infrared absorptions in a specified wavelength range of interest;

receive a second spectral measurement of a sample gas comprising a biogas in the sample cell, wherein the biogas includes one or more siloxane compounds;

generate a first absorption spectrum based on a ratio of the first spectral measurement and the second spectral measurement;

generate a set of surrogate absorption spectra based on, at least, individual absorption spectrum for each of a subset of one or more silicon-containing compounds selected from a larger set of known silicon-containing compounds with known concentrations; and

perform a multiple regression analysis using the first absorption spectrum and the set of surrogate absorption spectra to calculate a total concentration of the one or more silicon-containing compounds in the biogas.

33. The computer readable product of claim 32, wherein the digital processor is configured to determine the total concentration such that the set of surrogate absorption spectra is substantially similar to the first absorption spectrum.

CLAIMS

1. A method for monitoring one or more silicon-containing compounds present in a biogas, the method comprising:

providing a non-absorptive gas to a sample cell, the non-absorptive gas having substantially no infrared absorptions in a specified wavelength range of interest;

obtaining a first spectral measurement from the sample cell;

providing a biogas to the sample cell;

obtaining a second spectral measurement from the sample cell;

generating a first absorption spectrum based on a ratio of the first spectral measurement and the second spectral measurement;

generating at least one surrogate absorption spectrum based on, at least, individual absorption spectrum for each of a subset of one or more silicon-containing compounds selected from a larger set of known silicon-containing compounds with known concentrations; and

calculating a total concentration of the one or more silicon-containing compounds in the biogas based on the first absorption spectrum and the at least one surrogate absorption spectrum.

2. The method of claim 1, wherein the one or more silicon-containing compounds in the biogas include at least one siloxane.

3. The method of claim 1, wherein the larger set of known silicon-containing compounds includes at least one siloxane.

4. The method of claim 1, wherein the subset of one or more silicon-containing compounds includes at least one siloxane.

5. The method of claim 1, wherein the total concentration comprises one of a total concentration of siloxane compounds in the biogas, a total concentration of other silicon-containing compounds in the biogas or a total concentration of all silicon-containing compounds in the biogas.

6. The method of claim 1, further comprising applying a correction factor to the total concentration, wherein the correction factor scales the total concentration by a factor.

7. The method of claim 1, further comprising selecting the subset of one or more silicon-containing compounds based on spectral matching of the known silicon-containing compounds with the one or more silicon-containing compounds present in the biogas.

8. The method of claim 1, wherein the larger set of known silicon-containing compounds comprises D3-siloxane, D4-siloxane, D5-siloxane, D6-siloxane, L2-siloxane, L3-siloxane, L4-siloxane and L5-siloxane.

9. The method of claim 1, wherein the subset of one or more silicon-containing compounds comprises 3 to 5 siloxane compounds selected from the larger set of known silicon-containing compounds and the silicon-containing component of trimethyl silanol (TMS).

10. The method of claim 1, wherein the biogas comprises a landfill gas.

11. The method of claim 10, wherein the subset of one or more silicon-containing compounds comprises one of a) L2-siloxane, L3-siloxane and D4-siloxane; b) L2-siloxane, D3-siloxane and D4-siloxane; or c) L2-siloxane, D3-siloxane and D5 siloxane.

12. The method of claim 11, wherein the subset of one or more silicon-containing compounds further comprises the silicon-containing component of trimethyl silanol (TMS).

13. The method of claim 1, wherein the biogas comprises a digester biogas.

14. The method of claim 13, wherein the subset of one or more silicon-containing compounds comprises one of a) D3-siloxane, D5-siloxane and L3-siloxane; b) D4-siloxane, D5-siloxane and L3-siloxane; or c) D3-siloxane, D5-siloxane and L2-siloxane.

15. The method of claim 1, wherein the at least one surrogate absorption spectrum further comprises individual absorption spectrum for each of a subset of one or more hydrocarbon compounds selected from a larger set of known hydrocarbon compounds with known concentrations.

16. The method of claim 15, wherein the biogas comprises a digester gas and the larger set of known hydrocarbon compounds comprises ethane, propane and butane.

17. The method of claim 15, wherein the biogas comprises a landfill gas and the larger set of known hydrocarbon compounds comprises toluene, methanol and Ethanol.

18. The method of claim 15, wherein the at least one surrogate absorption spectrum is a model based on, at least, the individual absorption spectrum for each of the subset of one or more silicon-containing compounds and the individual absorption spectrum for each of the subset of one or more hydrocarbon compounds.

19. The method of claim 1, wherein at least one of the subset of one or more silicon-containing compounds is present in the biogas.

20. The method of claim 1, wherein at least one of the subset of one or more silicon-containing compounds is absent from the biogas.

21. The method of claim 1, wherein calculating comprises performing, using a processor, multiple regression analysis using the first absorption spectrum and the at least one surrogate absorption spectrum.

22. The method of claim 21, further comprising performing the multiple regression analysis using classical Least Square (CLS), Partial Least Squares (PLS), Inverse Least Squares (ILS), or Principal Component Analysis (PCA).

23. The method of claim 1, further comprising calculating, using a processor, the total concentration of the one or more silicon-containing compounds in the biogas in real-time and in-situ.

24. The method of claim 1, further comprising taking the second spectral measurement over an acquisition period of about 10 seconds to about 20 seconds.

25. The method of claim 1, further comprising determining a value for the total concentration of the one or more silicon-containing compounds such that the at least one surrogate absorption spectrum is substantially similar to the first absorption spectrum.

26. The method of claim 1, further comprising providing the biogas from animal waste, wastewater or a landfill.

27. The method of claim 1, wherein the total concentration is computed by representing spectral features of the one or more silicon-containing compounds in the biogas using a classical least square (CLS) fitting routine based on the first absorption spectrum, the at least one surrogate absorption spectrum and at least one of a baseline value or an offset value.

28. A system for monitoring one or more silicon-containing compounds in a biogas, the system comprising:

a source of a first beam of radiation;

an interferometer receiving the first beam of radiation from the source and forming a second beam of radiation comprising an interference signal;

a sample cell in optical communication with the interferometer;

a flow mechanism establishing a first flow of a non-absorptive gas having substantially no infrared absorptions in a specified wavelength range of interest and a second flow of the biogas through the sample cell;

a cooled detector in optical communication with the sample cell, the cooled detector receiving:

a first interference signal propagating through the non-absorptive gas in the sample cell; and

a second interference signal propagating through a sample gas in the sample cell, the sample gas comprising the biogas;

a processor in electrical communication with the cooled detector, the processor configured to calculate a total concentration of the one or more silicon-containing compounds in the biogas based on:

a first absorption spectrum based on a ratio of the first interference signal and the second interference signal;

a set of surrogate absorption spectra based on, at least, individual absorption spectrum for each of a subset of one or more silicon-containing compounds selected from a larger set of known silicon-containing compounds with known concentrations; and

a housing in which the source, the interferometer, the sample cell, the cooled detector and the processor are disposed.

29. The system of claim 28, wherein the one or more silicon-containing compounds in the biogas comprises at least one siloxane.

30. The system of claim 28, wherein the sample cell comprises:

a concave reflective field surface at a first end of the sample cell; and

a substantially spherical, concave reflective objective surface at a second end of the sample cell in a confronting relationship to the field surface, the objective surface having a cylindrical component increasing coincidence of foci in at least one plane to maximize throughput of the second beam of radiation propagating through the sample cell via multiple reflections on each of the field surface and the objective surface.

31. The system of claim 28, wherein the set of surrogate absorption spectra is a model based on, at least, the individual absorption spectrum for each of the subset of one or more silicon-containing compounds and individual absorption spectrum for each of a subset of one or more hydrocarbon compounds selected from a larger set of known hydrocarbon compounds with known concentrations.

32. A computer readable product, tangibly embodied on a non-transitory information carrier or a machine readable storage device, and operable on a digital signal processor for a biogas detection system, the computer readable product including instructions operable to cause the digital signal processor to:

receive a first spectral measurement of a non-absorptive gas in a sample cell, the non-absorptive gas having substantially no infrared absorptions in a specified wavelength range of interest;

receive a second spectral measurement of a sample gas comprising a biogas in the sample cell, wherein the biogas includes one or more siloxane compounds;

generate a first absorption spectrum based on a ratio of the first spectral measurement and the second spectral measurement;

generate a set of surrogate absorption spectra based on, at least, individual absorption spectrum for each of a subset of one or more silicon-containing compounds selected from a larger set of known silicon-containing compounds with known concentrations; and

perform a multiple regression analysis using the first absorption spectrum and the set of surrogate absorption spectra to calculate a total concentration of the one or more siloxane compounds in the biogas.

33. The computer readable product of claim 32, wherein the digital processor is configured to determine the total concentration such that the set of surrogate absorption spectra is substantially similar to the first absorption spectrum.