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Method and Apparatus for Treating Biogas

Abstract

A system for separating carbon dioxide from a biogas stream includes a first pipe and a second pipe extending within the first pipe. A first inlet at a first end of the second pipe receives the biogas stream, and a second inlet at a first end of the first pipe receives a liquid absorbent. The biogas stream is dispensed from the second pipe into the first pipe to mix with the liquid absorbent, separating the carbon dioxide from the biogas stream. A first outlet is in fluid communication with the first pipe to deliver a purified biogas stream. A first end of a third pipe extends from the first pipe and a second end of the third pipe extends into a mixed liquid absorbent stream within the first pipe. A second outlet, in fluid communication with the first end of the third pipe, delivers the mixed liquid absorbent stream.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation-in-part of, and claims priority to, U.S. Ser. No. 18/663,666, filed on May 14, 2024; which, in turn is a continuation of, and claims priority to, U.S. Ser. No. 17/198,572, filed on Mar. 11, 2021 which issued as U.S. Pat. No. 12,012,344 on Jun. 18, 2024; which, in turn, is a continuation-in-part of, and claims priority to, U.S. Ser. No. 16/725,426, filed Dec. 23, 2019, which issued as U.S. Pat. No. 11,268,063 on Mar. 8, 2022; which, in turn, is a continuation-in-part of, and claims priority to, U.S. Ser. No. 15/248,510, filed Aug. 26, 2016, which issued as U.S. Pat. No. 10,518,209 on Dec. 31, 2019; and which, in turn, claims priority to U.S. provisional application Ser. No. 62/211,494, filed Aug. 28, 2015, the entire contents of each application is incorporated herein by reference.

BACKGROUND OF THE INVENTION
[0002] The subject matter disclosed herein relates to a system for use in treating biogas and, more specifically, for a system to perform a separation process on biogas by which carbon dioxide is separated from methane in the biogas.
[0003] As is known in the art, one form of biogas is produced from anaerobic digestion and contains primarily methane (CH.sub.4) and carbon dioxide (CO.sub.2) with lesser quantities of other constituents. Methane may be present in an amount ranging from fifty to sixty-five percent (50-65%) by volume, carbon dioxide may be present in an amount ranging from thirty-five to fifty percent (35-50%) by volume, and the other constituents may include small percentages of nitrogen, oxygen, hydrogen sulfide, and other trace constituents. Other forms of biogas are produced from various biogenic processes such as the fermentation of certain carbohydrate-rich organic materials. For example, distilleries and ethanol facilities produce a mixture of biogases primarily comprised of carbon dioxide. Still other biogenic processes, such as biomass gasification or pyrolysis, may utilize heating and/or chemical processes on biomass feedstocks to form biogas.
[0004] As is also known in the art, it is desirable to separate the various biogas mixtures into the constituent gases. For the biogas produced from anaerobic digestion, it is desirable to separate the methane from the carbon dioxide and the other constituents to obtain a purified gas that may be used as a natural gas substitute. Several processes exist by which the methane and other gases can be separated from the biogas including, for example, a water wash process, chemical absorption, pressure swing absorption, and membrane separation.
[0005] During the water wash process, biogas is injected into water relying on the fact that carbon dioxide and hydrogen sulfide are many times more soluble in water than methane. The process typically occurs at an elevated pressure and reduced temperature to enhance the solubility of carbon dioxide and hydrogen sulfide in water. Historically, tall vessels have been constructed in which water is pumped into the top of the vessel and the biogas is pumped into the bottom of the vessel. As the biogas rises through the water, the carbon dioxide, hydrogen sulfide, and other water-soluble

trace constituents are absorbed into the water. Because the process is typically performed at an elevated pressure and at a lower temperature, the water and/or biogas is often chilled and/or compressed prior to entry into the vessel.

[0006] However, such systems have several drawbacks. The height of the vessels is substantial in order to provide sufficient time for the biogas to be in contact with the water and for the carbon dioxide to be absorbed into the water. Further, the material from which the vessel is made must be corrosion resistant due to the presence of hydrogen sulfide in the biogas and due to the carbonic acid formation from the carbon dioxide released during the process. The vessels are, therefore, typically constructed of stainless steel. The size and materials of the vessel as well as the volume of absorbent liquid within the vessels result in a substantial amount of weight for each vessel. This weight of the water wash treatment vessels requires a substantial physical foundation as well. The physical construction of the system as well as the materials from which the system are constructed are significant capital expenditures for these water wash treatment facilities.

[0007] Thus, it would be desirable to provide an improved system and method for performing the biogas separation process.

BRIEF DESCRIPTION OF THE INVENTION

[0008] The subject matter disclosed herein describes an improved system and method for performing the biogas separation process. The disclosed biogas separation process utilizes water or other chemical or biological liquid mixtures which absorb or separate carbon dioxide from a biogas, herein referred to as liquid absorbents. The biogas stream is introduced into a separation chamber with the liquid absorber. The separation chamber may have a number of different configurations, as described in more detail below. However, the separation chamber is configured to promote mixing of the biogas with the liquid absorbent such that the liquid absorbent either absorbs the carbon dioxide from the biogas or initiates a reaction causing the carbon dioxide to separate from the biogas.

[0009] According to one embodiment of the invention, the separation chamber may utilize a series of absorption risers. Each absorption riser may be installed above grade or, optionally, be configured to be installed below grade. The inlets for receiving a biogas stream and a water stream are located at a top end of the riser. The outlets for removing the purified gas stream and for removing the stream containing the carbon dioxide mixed with liquid absorbent are also located at the top end of the riser. By providing both the inlets and the outlets at the top end of the risers, the riser may be located substantially below grade such that the top end is accessible at or just above the ground level.

[0010] It is further contemplated that multiple absorption risers are provided. During installation, a trench may be dug and each of the absorption risers inserted into the trench. The trench may then be filled with absorption risers inserted in the trench. Each absorption riser may have a small diameter to facilitate digging of a trench. The diameter may typically be between about 4 inches and 48 inches for each riser. In one embodiment of the invention, the risers may be connected in series such that the output of one absorption riser is provided as an input to another absorption riser. In this manner, the biogas stream passes through a series of risers having an effective length much longer than a single riser. Each riser may be, for example, about 20 feet in length and the series connection of risers may be 100 feet or greater in length. In another embodiment of the invention, each absorption riser may be connected in parallel. In this manner a portion of the biogas stream is provided to each riser and the carbon dioxide extracted within a single riser. In a parallel connection, one or more of the absorption risers may be disconnected for cleaning or maintenance while allowing at least a portion of the system to continue operation. In still another embodiment of the invention, the absorption risers may be connected in a combination of serial and parallel connections. According to yet another embodiment of the invention, the risers may be configured in a generally horizontal plane. The riser may be a pipe, or multiple sections of pipe connected in series, to extend for tens or hundreds of feet in a continuous or looping configuration, providing sufficient time for the biogas to interact with the liquid absorbent for carbon dioxide separation as the two fluids pass through the horizontal riser.

[0011] In subsequent steps of the liquid absorbent wash process, the mixed absorbent stream may pass through one or more flash risers and/or air stripping risers. Each of the flash and air stripping risers may similarly be configured with each of the inlets and outlets located at a top end of the riser for installation below grade. The flash risers operate to remove gases. In this example, methane gas that was either absorbed with or simply exited the absorption riser with the mixed absorbent liquid is removed in the flash riser. The methane recovered from the flash risers is piped back and recirculated through the absorption risers to improve the quality of the purified biogas stream by increasing the percentage of methane recovery from the original biogas stream. The mixed liquid absorbent that remains after the flash riser includes primarily carbon dioxide. This mixed liquid absorbent may then be passed to the air stripping risers where the carbon dioxide is removed and the liquid absorbent may be recirculated and used again in the absorption process. Alternatively, the liquid absorbent may be regenerated by other means such as by thermal regeneration to drive off the carbon dioxide from the liquid absorbent or by the use of a gas-liquid membrane contactor to separate the carbon dioxide from the liquid absorbent. A contact liquid membrane may be provided within the flow of the mixed liquid absorbent to separate the liquid from the carbon dioxide gas. In still other applications with biological liquid absorbent mixtures the carbon dioxide portion of the biogas may be absorbed for example by microbes or plant species (e.g., algae) in wastewater treatment that metabolizes the carbon dioxide. The carbon dioxide feeds the biological process and simultaneously removes the carbon dioxide to produce a purified methane stream.

[0012] As such there are various biogas separating options that involve utilizing either chemical or biological liquid mixtures or combinations thereof. The various options of liquid absorbent allow more flexibility to collectively produce a purified methane stream, a carbon dioxide stream, and/or other gas streams based on initial constituents within the biogas. The present invention allows for this flexibility to use various liquid absorbents within the separation chamber of the present invention to remove the carbon dioxide from the biogas. Optionally, a first liquid absorbent may be used in a first riser, and a second liquid absorbent may be used in a second riser according to the desired constituent component to separate from the biogas stream.

[0013] According to one embodiment of the invention, a system for separating carbon dioxide from a biogas stream includes a first pipe and a second pipe. The first pipe and the second pipe each extend between a first end and a second end, and the second pipe extends within the first pipe. The first end of the second pipe is proximate the first end of the first pipe. A first inlet is present at the first end of the second pipe to deliver the biogas stream into the second pipe, and a second inlet is present at the first end of the first pipe to deliver a liquid absorbent into the first pipe. The biogas stream is dispensed from the second pipe to an interior of the first pipe, and the biogas stream mixes with the liquid absorbent within the first pipe to separate the carbon dioxide from the biogas stream, resulting in a purified biogas stream and a mixed liquid absorbent stream. A first outlet is in fluid communication with the first pipe to deliver the purified biogas stream from the first pipe. A third pipe extends into the first pipe, where the third pipe has a first end and a second end. The first end of the third pipe extends from the first pipe, and the second end of the third pipe extends into the mixed liquid absorbent stream within the first pipe. A second outlet is in fluid communication with the first end of the third pipe to deliver the mixed liquid absorbent stream.

[0014] According to another embodiment of the invention, a method for separating carbon dioxide from a biogas stream includes supplying a liquid absorbent to a first inlet in fluid communication with a first pipe and supplying the biogas stream to a second inlet in fluid communication with a second pipe. Both the first pipe and the second pipe have a first end and a second end. The first end of the second pipe is proximate the first end of the first pipe, the first inlet is at the first end of the first pipe, and the second inlet is at the first end of the second pipe. The biogas stream is delivered from the second pipe into first pipe. The biogas stream mixes with the liquid absorbent within the first pipe to separate the carbon dioxide from the biogas stream resulting in a purified biogas stream rising to a top of the first pipe and a mixed liquid absorbent stream flowing to a bottom of the first pipe. The purified biogas is dispensed from a first outlet located at the second end of the first pipe, and the mixed liquid absorbent stream is dispensed from a second outlet located at the second end of the first pipe, where the mixed liquid absorbent is drawn through a third pipe which extends into the first pipe and to the second outlet.

[0015] These and other objects, advantages, and features of the invention will become apparent to those skilled in the art from the detailed description and the accompanying drawings. It should be understood, however, that the detailed description and accompanying drawings, while indicating preferred embodiments of the present invention, are given by way of illustration and not of limitation. Many changes and modifications may be made within the scope of the present invention without departing from the spirit thereof, and the invention includes all such modifications.

Description

BRIEF DESCRIPTION OF THE DRAWING(S)

[0016] Various exemplary embodiments of the subject matter disclosed herein are illustrated in the accompanying drawings in which like reference numerals represent like parts throughout, and in which:

[0017] FIG. **1** is a block diagram representation of one embodiment of a water treatment system with integrated biogas treatment and carbon dioxide enhanced disinfection;

[0018] FIG. **2** is a block diagram representation of another embodiment of a water treatment system with integrated biogas treatment and carbon dioxide enhanced disinfection;

[0019] FIG. **3** is a block diagram representation of another embodiment of a water treatment system with integrated biogas treatment and carbon dioxide enhanced disinfection;

[0020] FIG. **4** is a block diagram representation of another embodiment of a water treatment system with integrated biogas treatment and carbon dioxide enhanced disinfection;

[0021] FIG. **5** is a graphical representation of the concentrations of hypochlorous acid and hypochlorite generated in solution as a function of the pH level of the solution;

[0022] FIG. **6** is a schematic representation of an exemplary biogas treatment system incorporating one embodiment of the present invention;

[0023] FIG. **7** is a schematic representation of an exemplary biogas treatment system incorporating another embodiment of the present invention;

[0024] FIG. **8** is a schematic representation of an exemplary biogas treatment system incorporating another embodiment of the present invention;

[0025] FIG. **9** is a schematic representation of an exemplary biogas treatment system incorporating another embodiment of the present invention;

[0026] FIG. **10** is a front view of one embodiment of an absorption riser from the biogas treatment system of FIG. **6**;

[0027] FIG. **11** is a front view of another embodiment of an absorption riser from the biogas treatment system of FIG. **6**;

[0028] FIG. **12** is a front view of a flash riser from the biogas treatment system of FIG. **6**;

[0029] FIG. **13** is a front view of an air stripping riser from the biogas treatment system of FIG. **1**;

[0030] FIG. **14** is a sectional view of the absorption riser of FIG. **10** taken at A-A′ illustrating one embodiment of a packing material incorporated into the absorption riser;

[0031] FIG. **15** is a sectional view of the absorption riser of FIG. **10** taken at A-A′ illustrating another embodiment of a packing material incorporated into the absorption riser;

[0032] FIG. **16** is an exemplary application incorporating one embodiment of the present invention;

[0033] FIG. **17** is a side elevation view of one embodiment of a discharge pipe for releasing carbon dioxide removed from the biogas stream;
[0034] FIG. **18** is a side elevation view of another embodiment of a discharge pipe for releasing carbon dioxide removed from the biogas stream;
[0035] FIG. **19** is a side elevation view of another embodiment of a discharge pipe for releasing carbon dioxide removed from the biogas stream;
[0036] FIG. **20** is a schematic representation of an exemplary biogas treatment system incorporating a horizontal absorption riser according to another embodiment of the present invention;
[0037] FIG. **21** is a schematic representation of an exemplary biogas treatment system incorporating a horizontal absorption riser according to another embodiment of the present invention;
[0038] FIG. **22** is a schematic representation of an exemplary biogas treatment system incorporating a horizontal absorption riser according to another embodiment of the present invention;
[0039] FIG. **23** is a partial sectional view of the horizontal absorption riser of FIG. **20** according to one embodiment of the invention;
[0040] FIG. **24** is a partial sectional view of the horizontal absorption riser of FIG. **20** according to another embodiment of the invention;
[0041] FIG. **25** is schematic representation of one embodiment of a polishing process incorporated into the biogas treatment system of FIG. **6**; and
[0042] FIG. **26** is schematic representation of another embodiment of a polishing process incorporated into the biogas treatment system of FIG. **6**.
[0043] In describing the preferred embodiments of the invention which are illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, it is not intended that the invention be limited to the specific terms so selected and it is understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose. For example, the word “connected,” “attached,” or terms similar thereto are often used. They are not limited to direct connection but include connection through other elements where such connection is recognized as being equivalent by those skilled in the art.
Detailed Description of the Preferred Embodiments
[0044] The various features and advantageous details of the subject matter disclosed herein are explained more fully with reference to the non-limiting embodiments described in detail in the following description.
[0045] Turning initially to FIG. **1**, one embodiment of a water treatment system **500** with integrated biogas treatment **510** and chlorine disinfection **520** is illustrated. Initial steps in the water treatment system **500** may include, for example, sedimentation, biological, and filtration processes. Still other steps may be included, but are not shown for ease of illustration. A flow of secondary treated wastewater **525** is received at a first basin **530**. Optionally, the secondary treated wastewater **525** may result from some or all of the initial steps discussed above being performed in the first basin on water to be treated. A first portion **532** of the secondary treated wastewater **525** is provided to the biogas treatment process **510**, and a second portion **534** of the secondary treated wastewater **525** is provided to the chlorine disinfection process **520** which is illustrated as occurring in a second basin **540**.
[0046] With reference also to FIGS. **2-4**, it is contemplated that the present invention may be integrated into various configurations of water treatment systems. In FIG. **2**, the secondary treated wastewater **525** is again supplied to or produced within the first basin **530**. A first portion **532** of the secondary treated wastewater is supplied to the biogas treatment process **510** and a second portion **534** of the secondary treated wastewater is provided to the second basin **540** for chlorine disinfection. In FIGS. **3** and **4**, it is contemplated that the first basin may be a prior basin or other

reservoir in the wastewater treatment process and the first basin is not expressly shown. Rather, the secondary treated wastewater **525** is supplied from the earlier steps in the water treatment system **500**, which are not shown, and provided to the illustrated portions of the water treatment system. In FIG. **3**, it is contemplated that the entire supply of secondary treated wastewater **525** may be provided as the second portion **534** to the second basin **540**. A secondary supply of water **536** is provided to the biogas treatment process **510** rather than diverting a first portion **532** from the secondary treated wastewater **525**. In FIG. **4**, again there is no explicitly illustrated basin for the secondary treated wastewater **525**, however, the secondary treated wastewater **525** supply is again divided into a first portion **532** supplied to the biogas treatment process **510** and a second portion **534** supplied to the chlorine disinfection process. Because the output of the biogas treatment process is a carbon dioxide water stream **518**, as discussed in more detail below, where the carbon dioxide water stream **518** includes water from either the first portion **532** of the secondary treated wastewater **525** or from the secondary supply of water **536** and carbon dioxide dissolved into that water, the first portion **532** of secondary treated wastewater **525** that is initially diverted through the biogas treatment **510** will still be disinfected in the chlorine disinfection process **520** when the carbon dioxide water stream **518** enters the second basin **540**. Although discussed above, secondary treated wastewater **525** in this description is not intended to be limiting. It is understood that the secondary treated wastewater **525** may be any water having a high pH value which requires a reduction in the pH level via the regulation process described in more detail below.

[0047] Although FIGS. **1-4** illustrate different embodiments of a water treatment system **500** integrating biogas treatment **510** and chlorine disinfection **520**, these embodiments are intended to be illustrative and not exhaustive of different configurations of water treatment systems **500**. It is contemplated that different arrangements of water treatment systems **500** may be utilized and the features shown in the illustrated embodiments may be arranged in different combinations without deviating from the scope of the invention.

[0048] With reference again to FIG. **1**, the chlorine disinfection process **520** receives chlorine at a chlorine injection point **550** from a chlorine supply. It is contemplated that the chlorine supply may be of multiple different forms, where chlorine is part of a chemical compound or supplied as chlorine gas. However, according to one embodiment the chlorine supply is provided in a mixture form of either sodium hypochlorite (NaClO) or as calcium hypochlorite (Ca(OCl).sub.2). Both sodium hypochlorite supplied in a liquid form and calcium hypochlorite supplied in a solid form are relatively stable and are safer to use for the disinfection process **520**. Both are less concentrated than pure chlorine gas. As a result, the liquid or solid mixtures do not emit airborne chlorine as readily as pure chlorine gas, reducing the risk to personnel operating the disinfection process. When the chlorine gas, sodium hypochlorite, or calcium hypochlorite is added to water, they generate concentrations of both hypochlorous acid and hypochlorite. With reference to Table 1 below and to FIG. **5**, the relative concentrations of hypochlorous acid and hypochlorite are shown as the percentage of overall chlorine present for disinfection as a function of the pH level of the water to be treated.

TABLE-US-00001 TABLE 1 Exemplary Percentages of Hypochlorous acid (HOCl) and Hypochlorite (OCl.sup.−) % HOCl % OCl.sup.− % HOCl % OCl.sup.− pH 32° F. (0° C.) 32° F. (0° C.) 68° F. (20° C.) 68° F. (20° C.) 4 100.0 0.0 100.0 0.0 5 100.0 0.0 97.7 2.3 6 98.2 1.8 96.8 3.2 7 83.3 16.7 75.2 24.8 8 32.3 67.8 23.2 76.8 9 4.5 95.5 2.9 97.1 10 0.5 99.5 0.3 99.7 11 0.05 99.95 0.03 99.97

[0049] As illustrated in FIG. **5** and Table 1 above, the percent concentration of hypochlorous acid and hypochlorite generated when the chlorine is injected into the water to be treated is about equal when the water has a pH level of about 7.5. As the pH level decreases, the percent concentration of hypochlorous acid increases and the percent concentration of hypochlorite decreases. The shift in concentration of hypochlorous acid versus hypochlorite is significant because the effectiveness of the two compounds for disinfection is substantially different. Hypochlorous acid has about twenty to one hundred (20-100) times the effectiveness of killing pathogens or causing the pathogens to become inactive when compared to a similar concentration of hypochlorite in water. Consequently, a smaller volume of hypochlorous acid than hypochlorite is required to provide the same level of disinfection of the water to be treated.

[0050] As also illustrated in FIG. **5** and Table 1 above, when the chlorine supply is injected into the water to be treated, the chlorine will take the form of either the hypochlorous acid or hypochlorite and their respective form of the chlorine will be dependent on the pH level of the water. The concentration of hypochlorous acid and hypochlorite will vary as the pH level rises above or goes below 7.5, but the combination of the two pH dependent forms of chlorine will always sum to one hundred percent. Within a range of pH levels from about 6 to about 9, the concentrations change from almost entirely generating one form of chlorine to almost entirely generating the other form of chlorine in water. For example, at a pH level of 6, the concentration of hypochlorous acid generated as a percent of this first available chlorine form is about ninety eight percent (98%) and the concentration of hypochlorite generated as a percent of this available chlorine form is about two percent (2%). Conversely, at a pH level of 9, the concentration of hypochlorous acid generated as a percent of the available chlorine form is about four percent (4%) and the concentration of hypochlorite generated as a percent of this second available chlorine form is about ninety-six percent (96%). Thus, a small change in the pH level of the water to be treated can have a significant impact on the effectiveness of the disinfection process.

[0051] Additionally, a step in the water treatment process **500** which is not illustrated in FIG. **1**, involves neutralization of residual chlorine in the treated water **560** discharged from the chlorine disinfection process **520**. Neutralization of residual chlorine is performed by the addition of another chemical, such as sodium bisulfite (NaHSO.sub.3) or sulfur dioxide gas (SO.sub.2). The amount of sodium bisulfite or sulfur dioxide gas required is proportional to the residual amount of chlorine present in the effluent discharge. As a result, if the pH level is controlled to maximize generation of hypochlorous acid, thereby minimizing the amount of sodium or calcium hypochlorite which is required, the amount of sodium bisulfite or sulfur dioxide required to neutralize residual chlorine can be similarly minimized. Thus, regulating the level of pH in the secondary treated wastewater **525** to be disinfected improves efficiency of the disinfection process **520** and reduces the volume of chemicals required, and therefore the cost, both at the initial stage (injection of chlorine) and potentially at dichlorination (removal of residual chlorine), the final step of the disinfection process.

[0052] Turning next to FIGS. **2** and **3**, it is contemplated that the chlorine injection point **550** may be provided at various locations in the water treatment system **500**. As shown in FIG. **2**, the chlorine injection point **550** is provided at the carbon dioxide water stream **518** being transferred between the biogas treatment process **510** and the chlorine disinfection process **520**. As shown in FIG. **3**, the chlorine injection point **550** is at the biogas treatment process **510**. Injection of the chlorine directly into the carbon dioxide water stream **518** or into the biogas treatment process **510** which ultimately generates the carbon dioxide water stream **518** such that the chlorine is delivered in tandem with the carbon dioxide water stream **518** may provide additional benefits of hypochlorous acid generation. As discussed in more detail below, the secondary treated wastewater **525** may have an initial pH in a range between seven and nine (7-9). The carbon dioxide water stream **518** may have a pH in the range of five to six and one-half (5-6.5). While the carbon dioxide water stream **518** is used to lower the pH range of the secondary treated wastewater **525**, injecting the chlorine directly into the carbon dioxide water stream **518** allows generation of hypochlorous acid where the pH level in the carbon dioxide water stream may result in nearly one hundred percent (100%) of the available chlorine to form the hypochlorous acid. In addition, the biogas treatment system **510** may utilize a long pipe or coil of piping in the water wash process, which may range up to five hundred feet long and result in contact with the water during the biogas treatment process for times up to or exceeding one to two minutes. This extended period of contact with the water forming the carbon dioxide water stream provides additional mixing time and additional time for the sodium or calcium hypochlorite to generate hypochlorous acid before introduction into the second basin **540**, providing more thorough and more efficient usage of the sodium hypochlorite or calcium hypochlorite.

[0053] Turning again to FIG. **1**, a pH sensor **580** is included in the second basin **540** for the disinfection process **520**. The pH sensor **580** generates a signal **582** corresponding to the pH level of the water present in the second basin **540**. The signal **582** is provided to a controller **570** which is configured to regulate the pH level in the second basin **540** during the disinfection process **520**. According to one embodiment of the invention, the controller **570** is an industrial controller such as a programmable logic controller (PLC). The controller includes a control program, or series of instructions, stored in non-transitory memory, such as a hard-drive, an optical drive, a magnetic drive, a solid-state drive, or the like. The control program, or series of instructions, is executed by a processor in the PLC. It is contemplated that a single storage device, or multiple storage devices, may be provided in the PLC. Similarly, a single processor or multiple processors or processing cores, configured to execute synchronously or asynchronously, may be provided. The industrial controller **570** receives input signals, such as the signal corresponding to the pH level in the second basin **540**, and generates output signals to control operation of the water treatment system **500**. It is further contemplated that a single controller **570** may control the entire system or separate controllers **570** may be provided at different portions of the water treatment system **500**. For example, a first controller **570** may control the biogas treatment process **510**, a second controller **570** may control upstream steps in the water treatment process, and a third controller **570** may control the disinfection process **520** and manage the pH level in the second basin **540**. Each controller **570** may be in communication with the other controller to transfer signals corresponding to operation of the water treatment system **500** as required by each controller.

[0054] According to the embodiment illustrated in FIG. **1**, it is contemplated that a pump and valve or other flow control device may be provided at the output of the biogas treatment process **510** or along the piping carrying the carbon dioxide water stream **518** from the biogas water treatment process to the disinfection process **520**. The controller **570** receives the signal corresponding to the pH level in the second basin **540** and adjusts a flow rate of the carbon dioxide water stream **518** to achieve a desired pH level in the second basin **540**. As discussed in more detail below, it is contemplated that the carbon dioxide water stream **518** may be pressurized and/or chilled as a result of the biogas treatment process **510**. Pressurization and/or refrigeration of the water used in the biogas treatment process **510** allows for supersaturation of carbon dioxide in the carbon dioxide water stream **518**. Different pressure levels and temperatures as well as differing amounts of carbon dioxide being removed from the biogas during the biogas treatment process **510** may result in varying levels of carbon dioxide present in the carbon dioxide water stream **518**. A second pH sensor **584** may be provided to measure the pH level of the carbon dioxide water stream **518**. The second pH sensor **584** also generates a signal **586** provided to the controller **570**, and the controller **570** may further adjust the flow rate of the carbon dioxide water stream **518** as a function of both the pH level in the second basin **540** and of the pH level of the carbon dioxide water stream **518**.

[0055] Alternately, or in addition, to the pH sensor **584** one or more additional sensors may be provided to measure process variables. For example, a sensor such as an oxidation reduction potential (ORP) sensor may be used to determine the relative amount of chlorine disinfection capability present in the water. An ORP sensor in a chlorine disinfection system provides a scaled indication of the amount of hypochlorous acid present, which is directly related to the pH level of the water being treated. The higher the value of a feedback signal from the ORP the greater the oxidation potential for disinfection purposes and the lower the value of the pH. As a result, the feedback signal from the ORP sensor may be provided to the controller **570** in addition or in place of the feedback signal from a pH sensor **584**. The feedback signal for the ORP sensor corresponds to a disinfecting strength present in the second basin **540** as it detects the ability of a solution to act as a reducing agent which is a function of the relative levels of hypochlorous acid and hypochlorite as illustrate in FIG. **5**. The feedback signal from the ORP sensor may be used by itself or combination with the feedback signal from the pH sensor to control injection of the carbon dioxide water stream **518** into the second basin **540** to increase the level of hypochlorous acid as a percent of the available chlorine available for disinfection.

[0056] With reference again to FIG. **2**, it is contemplated that the carbon dioxide water stream **518** may be delivered into the second basin **540** with multiple injection devices or nozzles **590**. Each nozzle **590** is located at a different depth within the second basin **540**. When the carbon dioxide water stream **518** enters the water to be treated, the carbon dioxide is released from carbon dioxide water stream **518**. The amount of carbon dioxide carried within the carbon dioxide water stream **518** will vary as a function of the pressure at which the carbon dioxide water stream **518** is maintained. When the carbon dioxide water stream **518** is released into the basin **540**, the water in the basin to be treated is no longer under pressure and the extra carbon dioxide is released from the pressurized stream in the form of small gaseous bubbles within the water to be treated. The gaseous bubbles of carbon dioxide rise to the surface of the basin. A portion of the carbon dioxide mixes into the secondary treated wastewater **525** present in the second basin **540** and a portion of the carbon dioxide is released into the atmosphere. The efficiency of the mixing process is controlled in part by the amount of time the carbon dioxide is present in the basin **540**. Therefore, releasing carbon dioxide at a greater depth allows more time for the carbon dioxide to be in contact with and, therefore, to mix and absorb into the water in the basin **540**, causing a greater reduction in the pH level of the secondary treated wastewater **525** present in the second basin **540**. One or more injectors, or nozzles, can be used at different depths within the basin **540** or, alternately, a nozzle at or above the surface of the basin may be activated to inject or spray the secondary treated wastewater **525** into the second basin **540** as a function of the pH level in the basin **540** and/or the pH level present in the secondary treated wastewater **525**. The controller **570** may receive the feedback signal, or signals, **582**, **586** corresponding to the pH level in the second basin or in the carbon dioxide water stream and regulate operation of the nozzles to achieve a desired pH level.

[0057] According to still another aspect of the invention, it is contemplated that not all of the carbon dioxide water stream **518** produced by the biogas treatment **510** process may be required to regulate the pH level in the disinfection process **520** to a desired pH level. As discussed in more detail below, various embodiments of the biogas treatment process **510** may be configured to release excess carbon dioxide. The controller **570** may receive the feedback signal, or signals, **582**, **586** corresponding to the pH level in the second basin or in the carbon dioxide water stream and regulate operation of the carbon dioxide aeration or stripping process **300** to achieve a desired pH level.

[0058] Integration of the biogas process **510** into a water treatment system **500** results in the production of a purified methane stream, as discussed in more detail below, and a more efficient water treatment process by use of carbon dioxide supersaturated in water, which is a by-product of the biogas process **510**. According to an exemplary application, a wastewater treatment plant anaerobic digester produces 250 cubic feet per minute (cfm) of biogas where the biogas has a typical carbon dioxide (CO.sub.2) concentration of thirty-five percent (35%) on a volume basis and the balance of the biogas is methane. Based on the CO.sub.2 gas concentration and rate of production of biogas, the anaerobic digester would produce the equivalent of about 14,500 pounds (lbs.) per day or 7.25 tons per day of CO.sub.2. In this example, about ninety-five percent (95%) of the CO.sub.2 gas from the raw biogas is dissolved by the water wash process resulting in about 13,100 lbs or 6.5 tons per day of CO.sub.2 available for pH adjustment in the downstream chlorination disinfection process **520**. However, in an exemplary application, about seventy-five percent of the dissolved CO.sub.2 water may mix effectively to adjust the pH level in the disinfection process. As a result, about 9,800 lbs. or 4.9 tons of CO.sub.2 per day can be beneficially utilized from this biogas treatment process **510**.

[0059] The controller **570** measures a pH level in the disinfection process **520** of about 7.4, which results in approximately an even division of hypochlorous acid and hypochlorite being generated as available chlorine for disinfection. For the exemplary application, a desired pH level of 6.8 is selected. Based on chemical equilibrium and assuming an alkalinity of 100 mg/l in the secondary treated wastewater **525**, about 26 mg/l of additional CO.sub.2 is needed to lower the pH from 7.4 to 6.8 at a temperature of 65 deg F assuming the secondary treated wastewater has an initial CO.sub.2 concentration of 8 mg/l. With reference to Table 1 and FIG. **5**, lowering the pH level in the secondary treated wastewater from 7.4 to 6.8 would result in an effective increase in hypochlorous acid availability from about 55% to 80%. Based on the total additional 9,800 lbs per day of dissolved CO.sub.2 from this integrated biogas treatment process **510**, adjusting the pH level from 7.4 to 6.8, and using a pre-determined chlorine dosage rate (for that particular pH), about 45.19 million gallons per day of secondary treated wastewater **525** could be treated.

[0060] The above-described minor adjustment in the pH level allows for approximately a twenty-five percent (25%) reduction in the amount of chlorine required to achieve the desired disinfection due to increased levels of hypochlorous acid present. In addition, there could be approximately a twenty-five percent (25%) reduction in the amount of sodium bisulfite required to neutralize residual chlorine. This reduction in the pH level by using the carbon dioxide water stream **518** can result in significant annual cost savings for disinfection chemicals used in the water treatment plant operations.

[0061] Turning next to FIG. **6**, an exemplary biogas treatment system utilized in one embodiment of the present invention is illustrated. A biogas stream **10** is provided as an input to the system, where the biogas may be produced, for example, from an anaerobic decomposition process. The anaerobic decomposition process may, for example, convert food waste, sewage, animal manure, landfill waste and the like into biogas. The biogas primarily includes methane and carbon dioxide with a lesser percentage of other constituents, such as nitrogen, oxygen, and hydrogen sulfide. Methane is typically present in a concentration of fifty to sixty-five percent (50-65%) by volume and carbon dioxide is typically present in a concentration of thirty-five to fifty-five percent (35-50%) by volume. According to another example, the biogas may be produced from a biogenic process that includes fermentation processes. The fermentation process may, for example, be associated with distilleries or ethanol plants, and the resultant biogas may be comprised primarily of carbon dioxide. The exemplary biogas treatment system utilizes an absorbent liquid, where the absorbent liquid removes the carbon dioxide (CO.sub.2) and other trace constituents from the biogas.

[0062] According to one exemplary biogas treatment system, water is provided as the absorbent liquid. The water removes the carbon dioxide (CO.sub.2) and other trace constituents, such as hydrogen sulfide (H.sub.2S) and siloxanes, resulting in a purified biogas stream having a methane (CH.sub.4) content of up to about ninety-nine percent (99%) and carbon dioxide content as low as one percent (1%). The resulting purified biogas stream may be used as a replacement fuel for natural gas, for example, in a compressed natural gas vehicle engine or other natural gas fuel energy applications. Although the invention will be discussed primarily with respect to a water wash process for treating biogas, it is understood that the system may be used to treat other gas mixtures in which the relative solubility of one gas in the mixture is substantially higher than the other gas in the mixture. In addition, it is contemplated that other absorbent liquids may be utilized in the treatment process to perform separation of the gases.

[0063] Some initial processing of the biogas stream may occur prior to supplying the biogas stream to the wash system. An optional hydrogen sulfide (H.sub.2S) removal process **15** such as an iron sponge type system may be inserted in series with the biogas stream **10** to perform an initial removal of hydrogen sulfide present in the biogas stream. Because hydrogen sulfide is corrosive, removal of the gas at an initial stage limits the effects of the gas on the system components through the wash process. Optionally, hydrogen sulfide may be removed in the off-gas exhaust output from the stripping process. The biogas stream may also be passed through a filter **20** to remove particulate content. In addition, carbon dioxide has increased solubility characteristics with decreasing temperature and increasing pressure. The biogas stream is, therefore, passed through a compressor **25** to achieve an elevated pressure. The pressure range of the compressed biogas stream **30** may be between forty and two hundred pounds per square inch gauge (40-200 psig). According to one embodiment of the invention, the pressure range of the compressed gas is between about one hundred and one hundred-fifty pounds per square inch gauge (100-150 psig). The compressed biogas may also be chilled, for example, to between thirty-five and sixty-eight degrees Fahrenheit (35-68° F.). The compressed and/or chilled biogas stream **30** is provided as an input to the wash process.

[0064] The wash process utilizes a liquid absorbent to remove the carbon dioxide from the biogas stream. For ease of description, the wash process will be discussed herein as a water wash process. It is understood that various other liquid absorbents may be utilized in the wash process. Alternate liquid absorbents include, but are not limited to various forms and/or mixtures of hydroxides, carbonates, ammonia, amines, amino acids, propylene carbonate, ethylene glycol, polyethylene glycol, methanol, and alcohol. According to the illustrated embodiment, water is provided to a holding tank **40** from which a water stream **50** is provided to the water wash process. Water provided to the holding tank **40** may be chilled and/or under pressure to facilitate the water wash process. As discussed above, secondary treated wastewater **525** from a water treatment system **500** in which the biogas treatment process is integrated may be a source of water. The secondary treated wastewater **525** may be supplied to the holding tank **40** or directly input to the first riser **110**. Optionally, the holding tank **40** may incorporate a chiller and/or a compressor to chill or pressurize the water prior to supplying it in the water stream. The water, for example, may be chilled to between thirty-five and sixty-eight degrees Fahrenheit (35-68° F.) and pressurized to mix with the compressed biogas stream **30** at about the same input pressure of the compressed biogas stream. The carbon dioxide has significantly more solubility in water than methane and the solubility is further improved with increased pressure and reduced temperature. Thus, providing a chilled and/or pressurized water stream **50** and a compressed and/or chilled biogas stream **30** into the absorption risers **110** enhance the absorption of carbon dioxide from the biogas and into the water and, thereby also provide a super-saturated carbon dioxide water stream **518** from the biogas treatment process **510**.

[0065] The biogas separation process begins with an absorption process **100** that has multiple absorption risers **110** operatively connected together to remove the carbon dioxide from the compressed biogas stream **30**. Referring also to FIG. **10**, each absorption riser **110** includes multiple pipes. In the illustrated embodiment, the absorption riser **110** includes an outer pipe **112**, a first inner pipe **122**, and a second inner pipe **132**. According to the illustrated embodiment, each of the pipes is concentric to the others. Optionally, the first inner pipe **122** and the second inner pipe **132** may be positioned adjacent to each other or extend downward at different locations within the outer pipe **112**. The outer pipe **112** has a first end **114**, a second end **116**, and a first length, L**1**. The first inner pipe **122** has a first end **124**, a second end **126**, and a second length, L**2**. The second inner pipe **132** has a first end **134**, a second end **136**, and a third length, L**3**.

[0066] According to one embodiment of the invention, each of the absorption risers **110** are installed in a vertical orientation, such that the first ends **114**, **124**, **134** of each pipe **112**, **122**, **132** are generally positioned at the top of each absorption riser **110**. The first inner pipe **122** extends for the second length, L**2** into the outer pipe **112** such that the compressed biogas stream **30** may be delivered into a lower segment of the absorption riser **110**. According to the illustrated embodiment, the first inner pipe **122** is cylindrical and open at the second end **126**. The compressed biogas stream **30** flows from the first inlet **140** and exits at the second end **126** of the first inner piper **122**. The second inner pipe **132** extends for the third length, L**3**, through the first inner piper **122**, beyond the second end **126** of the first inner pipe **122**, and into the outer pipe **112**. The second inner pipe **132** is cylindrical and the second end **136** of the second inner pipe **132** includes a check valve between the interior of the outer pipe **112** and the interior of the second inner pipe **132**.

[0067] Each absorption riser **110** includes a set of inlets and outlets to allow water and biogas to flow into and out of the riser **110**. A first inlet **140** receives the compressed biogas stream **30** and is located on the first end **114** of the outer pipe **112**. The first inlet **140** is in fluid communication with the first end **124** of the first inner pipe **122** and establishes a flow path for the compressed biogas stream **30** into the absorption riser **110**. The first inner pipe **122** extends into the absorption riser **110** for the length, L**2**, of the inner pipe **122**. According to the embodiment illustrated in FIG. **10**, the second end **126** of the first inner pipe **122** terminates at a dispersion element **144** proximate the second end **116** of the first inner pipe **122**. A second inlet **145** receives the liquid absorbent stream **50** and is located on the first end **114** of the outer pipe **112**. The second inlet **145** is in fluid communication with the first end **114** of the outer pipe **112** to dispense the liquid absorbent stream **50** from the top of the absorption riser **110**. As will be discussed in more detail below, the liquid absorbent stream **50** is dispensed at the top of the interior of the absorption riser **110** via the second inlet **145** and the compressed biogas stream **30** is dispensed at the bottom of the interior of the absorption riser **110** via the first inner piper **122**, and the compressed biogas stream **30** passes up through the liquid absorbent stream **50** within the absorption riser **110**. As the liquid absorbent stream **50** falls to the bottom of the absorption riser **110** it mixes with the biogas stream and the carbon dioxide within the compressed biogas stream **30** is dissolved into the liquid absorbent. Although small amounts of methane may be absorbed in the liquid absorbent, the majority of the methane remains unabsorbed and rises to the top of the absorption riser **110**. Because carbon dioxide is removed from the compressed biogas stream **30** as it interacts with the liquid absorbent stream **50**, the flow of biogas resulting from mixing with the liquid absorbent will be referred to herein as a purified biogas stream **162**. Similarly, because the liquid absorbent stream **50** removes carbon dioxide from the compressed biogas stream **30**, the resulting liquid absorbent stream will be referred to herein as a mixed liquid absorbent stream **166**. When a particular liquid absorbent, such as water, is described, the liquid absorbent may be referred to as the identified absorbent, and the liquid absorbent stream **166** may be referred to as a mixed water stream.

[0068] According to the embodiment illustrated in FIG. **11**, the second end **126** of the first inner pipe **122** simply terminates within the outer pipe **112** without a dispersion element **144** located proximate the second end **126** of the first inner pipe **122**. The second end **126** of the first inner pipe **122** may be configured to disperse the compressed biogas stream **30** into water flowing within the outer pipe **112**. The dispersion may be achieved, for example, via a series of holes **127** located along the length of the first inner pipe **122** as shown in FIGS. **20-22**, via a nozzle, or series of nozzles positioned at the second end **126**, or via other dispersion methods which are integrally formed with the first inner pipe **122**. Optionally, a series of nozzles may be located along the length of the first inner pipe **122**, where each nozzle disperses a portion of the biogas stream within the outer pipe **112**. According to still another option, multiple inner pipes **122** may be provided, where each inner pipe **122** includes a series of holes **127** or nozzles spaced along the length of each inner pipe **122** to facilitate dispersion of the biogas stream **30** throughout the interior of the outer pipe **112**. It is contemplated that an optional dispersion element **146** may still be located within the outer pipe **112** at a location between the inlet of the water stream and the inlet of the compressed biogas stream within the absorption riser **110** if desired for further mixing of the two streams.

[0069] A first outlet **160** located at the first end **114** of the outer pipe **112** provides a flow path **161** for the purified biogas stream **162** to exit the absorption riser. The first outlet **160** is in fluid communication with and receives the purified biogas stream **162** from the interior of the outer pipe **112**. A second outlet **165** is also located proximate the first end **114** of the outer pipe **112** and provides a flow path **167** for the mixed water stream **166**. The second outlet **165** is in fluid communication with the first end **134** of the second inner pipe **132**. The mixed water stream **166** enters the second end **136** of the second inner pipe **132** and travels up through the second inner pipe **132** to the second outlet **165**. According to the illustrated embodiment, each of the outer pipe **112**, first inner pipe **122**, and second inner pipe **132** are concentric about a central axis. The second inner pipe **132** is located within the first inner pipe **122**, which is, in turn, located within the outer pipe **112**. As discussed above and for purposes of illustration in FIG. **10**, the first end **114**, **124**, **134** of each pipe **112**, **122**, **132** ends at substantially the same point. It is contemplated that in various embodiments the first end **124**, **134** of each of the first inner pipe **122** and the second inner pipe **132** may extend for a short distance beyond the first end **114** of the outer pipe **112** to facilitate connections between each pipe and an inlet or outlet. It is further contemplated that an inlet **140**, **145** or outlet **160**, **165** may be positioned along and enter the outer pipe **112** via a side wall proximate the end of the absorption riser **110**. For example, the first inlet **140** is shown connecting generally orthogonally to a wall of the first inner pipe **122** beyond the first end **114** of the outer pipe and the second inner pipe **132** extends through an end wall of the first inner pipe **122** to connect to the second outlet **165**. Alternately, the first inlet **140** or second outlet **165** may include a fixture connected to the first end **114** of the outer pipe **112** and comprise the necessary connections to establish the fluid flow paths from the inlet and outlet to the inner pipes extending into the outer pipe **112**.

[0070] With reference again to FIG. **10**, each absorption riser **110** may also include one or more dispersion elements located within the flow path to facilitate mixing of the compressed gas stream **30** with the water stream **50**. A first dispersion element **149** is located in the flow path **147** of the water stream **50** as it exits the second inlet **145**, and a second dispersion element **144** is located in the flow path **142** of the compressed gas stream **30** as it exits the second end **126** of the first inner pipe **122**. Each dispersion element **144**, **149** is operable to distribute either the compressed gas stream **30** or the water stream **50** throughout the interior of the outer pipe **112**. According to the illustrated embodiment, each dispersion element **144**, **149** is a diffuser plate, where the diffuser plate extends around the first inner pipe **122**, forming a disk within the interior or the outer pipe **112**. The diffuser plate includes multiple holes extending through the plate which allow the water and gas to flow through. The holes are distributed around the surface of the disk such that water and gas flow through and are distributed throughout the interior of the outer pipe **112**.

[0071] With reference again to FIG. **11**, it is contemplated that one or more of the dispersion elements are optionally included within the absorption riser. It is contemplated that other methods of distributing the compressed gas stream **30** and/or the water stream **50** within the absorption riser may be utilized without deviating from the scope of the invention. For example, one or more sparging tubes may be operatively connected to the second inlet **145** or to the second end **126** of the first inner pipe **122** and arranged within the interior of the outer pipe **112** to distribute the water and gas throughout the interior of the outer pipe **112**. According to still another embodiment, spray nozzles may be operatively connected to the second inlet **145** or to the second end **126** of the first inner pipe **122** to discharge the water and gas as a mist throughout the interior of the outer pipe **112**. An additional dispersion element **146**, may be included within the combined streams if desired for further mixing of the water stream **50** with the compressed gas stream **30**. According to still other embodiments, various combinations of dispersion elements may be utilized. Each dispersion element distributes the water and gas in finer jets, flows, or droplets to increase the surface area of water and gas present within the outer pipe **112**. The increased surface area of water and gas increases the area at which the water and gas may contact each other and thereby increasing the area across which carbon dioxide may transfer from the compressed biogas stream **30** to the water stream **50**.

[0072] It is further contemplated that each absorption riser may include packing material within at least a portion of the interior of the outer pipe **112** to further enhance the mixing of the compressed biogas stream **30** with the water stream **50**. In FIG. **10**, an additional dispersion plate **146** is shown. One or more additional dispersion plates **146** may be distributed along the length of the interior of the outer pipe **112** to continually redistribute the gas and water as they travel through the interior of the pipe. With reference also to FIGS. **14** and **15**, other packing material may be inserted into the outer pipe **112**. In FIG. **14**, a flexible material **170** is rolled into a coil and inserted between the inner periphery of the outer pipe **112** and the outer periphery of the first inner pipe **122**. According to one embodiment of the invention, the flexible material **170** is a netting material, such as a geonet, including multiple holes throughout the material. As the liquid absorbent and gas pass through the absorption riser **110**, the netting and the multiple holes create numerous flow paths and opportunities for collisions and, thereby, increasing contact surface area between the liquid absorbent and biogas for transfer of the carbon dioxide from the biogas to the liquid absorbent. In FIG. **15**, a mesh material **180** may be formed into a basket or bag and is used to contain another bulk material **182** within the mesh. The bulk material is preferably a material that allows the liquid absorbent and gas to flow through while increasing contact between the liquid absorbent and gas. Optionally, the bulk material may be a medium that has absorptive characteristics such as activated carbon or zeolites which may further aid in the removal of trace constituents from the pressurized biogas stream **30**. The mesh and bulk materials **180**, **182** may be inserted into and removed from the interior of the outer pipe **112** as a unit. Both the flexible material **170** and the mesh and bulk material combination **180**, **182** facilitate cleaning of the packing material. The flexible material **170** may be removed and unrolled for cleaning. The mesh and bulk material **180**, **182** may be pulled out of the outer pipe **112** and the bulk material spread out for cleaning. Once clean, the flexible material **170** may be rolled back into a coil and inserted back into the outer pipe **112**. Similarly, the bulk material **182** may be placed back into the mesh material **180** and inserted into the outer pipe **112**.

[0073] With reference again to FIG. **6**, it is contemplated that multiple absorption risers **110** may be connected in series. The effect of connecting the absorption risers **110** in series is to create an overall longer length of pipe greater than the length of a single riser through which the compressed biogas stream **30** interacts with the liquid absorbent stream **50**, allowing for a greater concentration of carbon dioxide to be transferred from the pressurized biogas stream **30** to the liquid absorbent stream **50**. One of the absorption risers **110** is designated as an initial absorption riser in the system and receives the initial input of the pressurized biogas stream at the first inlet **140** and the liquid absorbent stream **50** at the second inlet **145**. The first outlet **160** of the initial absorption riser is connected to the first inlet **140** of another absorption riser **110** and the second outlet **165** of the initial absorption riser is connected to the second inlet **145** of the other absorption riser **110**. This sequence of connections repeats for each absorption riser in the system until a final absorption riser is reached. At the final absorption riser, the first inlet **140** still receives the biogas stream from the first outlet **160** of the preceding absorption riser and the second inlet **145** receives the liquid absorbent stream from the second outlet **165** of the preceding riser. However, the first outlet **160** of the final absorption riser provides the purified biogas stream **162** and the second outlet **165** of the final absorption riser provides the mixed liquid absorbent stream **166**. As the biogas and liquid absorbent streams progress through each absorption riser, the concentration of carbon dioxide in the biogas stream is incrementally reduced and the concentration of carbon dioxide in the liquid absorbent stream is incrementally increased from the starting level at the initial absorption riser to the final levels at the final absorption riser. Optionally, different liquid absorbents may be utilized in different risers according to the desired gas constituent to be separated from the pressurized biogas stream.

[0074] With reference next to FIG. **7**, it is also contemplated that multiple absorption risers **110** may be connected in parallel. Each of the compressed biogas stream **30** and the liquid absorbent stream **50** are split and portions of each stream are supplied to each riser. As illustrated, the pressurized biogas stream **30** is provided to the first inlet **140** of each absorption riser **110**, and the liquid absorbent stream **50** is provided to the second inlet **145** of each absorption riser **110**. The first outlet **160** of each absorption riser is connected to a junction at which the purified biogas stream **162** from each absorption riser is combined and delivered from the system. Similarly, the second outlet **165** of each absorption riser is connected to a second junction at which the mixed liquid absorbent stream **166** from each absorption riser is combined and may be transferred for further processing. To achieve comparable purifying performance to the serial connection discussed above, the volume of biogas introduced into each absorption riser **110** may be split between each absorption riser while the volume of liquid absorbent introduced into each riser remains the same. Thus, a greater volume of liquid absorbent per unit is available for interaction with the same volume of biogas, allowing a greater percentage of the carbon dioxide to be removed in a single absorption riser than when the entire flow of biogas enters a single riser.

[0075] According to still another aspect of the invention, it is contemplated that the absorption risers **110** may be connected in a combination of serial and parallel connections. For example, two or three absorption risers **110** may be connected in series as a set of absorption risers with multiple sets of absorption risers connected in parallel. Alternately, the biogas stream **30** may enter a first absorption riser **110** and pass through subsequent absorption risers in series and the liquid absorbent stream **50** may be supplied to the absorption risers in parallel, thereby maximizing the transfer of carbon dioxide from the biogas stream to the liquid absorbent stream at each riser.

[0076] In addition to determining whether to connect the absorption risers **110** in series or parallel, a number of other design criteria are considered when configuring the wash system. As previously discussed, the gas and/or liquid absorbent stream may be cooled or compressed. Further, the diameter and length of each absorption riser **110** is evaluated. In addition, the material from which the absorption riser is constructed must be determined.

[0077] As an exemplary application, and existing water wash system may utilize a single stainless steel vessel with a height ranging from twenty to sixty feet and a diameter up to six feet. The size of the vessel, the materials from which it is constructed and the weight of the water and biogas within the vessel further requires structural considerations such as a reinforced concrete footing to support the weight and horizontal stabilization members to prevent tipping.

[0078] In contrast, the absorption risers **110** of the present system are constructed from a non-metallic material and, preferably, are constructed of a plastic or reinforced resin material. According to one embodiment of the invention, the risers are made from a polyethylene material, such as high density polyethylene (HDPE) or medium density polyethylene (MDPE), or from a polyamide material. Optionally, the risers may be made from polyvinyl chloride (PVC) or fiberglass. The materials are lighter and less expensive than existing materials, reducing system costs and making construction easier.

[0079] With reference next to FIG. **16**, an exemplary installation of one embodiment of the present invention at a farm is illustrated. The farm includes an anaerobic digester **11** to break down animal waste created on the farm. The raw biogas stream **10** output from the anaerobic digester **11** is provided to an initial processing stage **12**. With reference also to FIG. **6**, the initial processing stage **12** may include the hydrogen sulfide cleaner **15**, filter **20**, and compressor **25**. The initial processing stage, therefore, removes hydrogen sulfide from the raw biogas stream **10** and then filters and compresses the biogas stream, providing a compressed biogas stream **30** to a series of absorption risers **110**, a flash riser **210**, and an air stripping riser **310**.

[0080] Each of the risers **110**, **210**, **310** are installed in a trench **13** and substantially below grade. The diameter of each riser is preferably in the range of four to thirty inches (4-48 in.) and the length may be, for example twenty feet (20 ft.). The trench may be dug using conventional excavation methods and each riser inserted within the trench. Optionally, an auger may be used to drill individual holes into the ground and each riser is inserted into one of the holes. The top of each riser is at or above grade to provide for connection of tubing and fittings for transmitting biogas and/or liquid absorbent to and from each riser. After each riser is installed within the trench **13** or hole, the trench or hole may be back-filled so the earth surrounds each riser. The earth surrounding each riser provides a number of benefits, such as protection from ultraviolet radiation in outdoor installations, insulation for the chilled liquid absorbent, and physical support for each riser when it is filled with biogas and liquid absorbent. In alternate embodiments of the invention, it is contemplated that the risers may be installed below grade, above grade, or a combination thereof. When either a portion or all of a riser is installed above grade, it is contemplated that one or more exterior sleeves may cover the portion of the riser above grade. Each sleeve may provide ultraviolet (UV) ray protection, insulation, support, or a combination thereof for the portion of the riser that is above grade and no longer protected, insulated, or supported by the ground. According to still other embodiments of the invention, a riser may be submerged in water, where the water similarly provides some UV ray protection, insulation and support for the submerged risers. Optionally, one or more exterior sleeves may be used in combination with submerging each riser to further protect, insulate, or support each riser.

[0081] When a water wash system is selected, the system requires a supply of water by which the carbon dioxide is removed from the biogas stream. In some applications, such as a waste water treatment system, there may be a continuous supply of process water, such as the secondary treated wastewater **525**. In the illustrated embodiment, a holding tank **40** is provided to supply the water. Water may be drawn from a pond or lake or otherwise be supplied from a well or from a municipal water supply. As previously discussed, the water may be chilled and/or compressed prior to being pumped to the absorption riser **110**.

[0082] The water stream **50** and compressed gas streams each enter the top of each absorption risers **110** in a series arrangement as also shown in FIG. **6**. A portion of the carbon dioxide is transferred from the compressed biogas stream **30** to the water stream **50** in each absorption riser **110**. The compressed biogas stream **30** travels down a pipe to the lower portion of the absorption riser and the water stream **50** enters the top of the absorption riser. The compressed biogas rises and the water falls within each absorption riser **110**, creating contact between the two streams. The partly purified biogas stream exits a first outlet **160** at the top of the initial absorption riser, and the mixed water stream **166** is internally pumped from the bottom of the absorption riser **110** to the top and exits a second outlet **165** also at the top of the absorption riser. Each subsequent absorption riser **110** in the series receives the partly purified biogas stream and mixed water stream from the prior absorption riser at the inlets and transfers additional carbon dioxide from the biogas stream to the water stream. The final absorption riser **110** contains the purified biogas stream which exits at the first outlet **160**. According to the illustrated embodiment, the purified biogas stream **162** is provided to a storage tank **14** from which it may be used as a fuel. According to other embodiments and as illustrated in FIGS. **6-9**, the purified biogas stream **162** may undergo some additional processing prior to use. For example, a first moisture removal vessel **26** and/or a subsequent desiccant dryer **27** may be provided to remove water from the purified biogas stream **162**. Still other processing steps may be provided for polishing the gas to remove, for example, trace constituents or additional carbon dioxide still remaining in the biogas stream **162**.

[0083] With reference also to FIGS. **25** and **26**, two exemplary polishing processes **28** are illustrated. In FIG. **25**, the polishing process **28** uses a liquid polishing agent **82** which is a carbon dioxide (CO.sub.2) absorbent. According to one aspect of the invention, the polishing agent is an alkali material comprised of a hydroxide compound such as calcium hydroxide, sodium hydroxide, or potassium hydroxide. Optionally, the polishing agent may be an oxide compound such as calcium oxide. For purposes of discussion calcium hydroxide will be discussed in the form of a liquid polishing agent **82**, however, this is not intended to be limiting. The calcium hydroxide is introduced into a first holding tank **80**. The calcium hydroxide may be delivered directly to the first holding tank **80** in a liquid form as a mixture or solution. Optionally, the calcium hydroxide may be first introduced into the holding tank **80** in a solid form, for example, as powder and water, or other suitable liquid carrier, also introduced into the holding tank **80**. A mixer may be used to combine the granules and the water into a solution suitable for delivery to the polishing tank **85**. The liquid calcium hydroxide **82** is then delivered to an inlet **83** on the polishing tank **85**.

[0084] Within the polishing tank **85**, the polishing agent interacts with the purified biogas stream

162 to further remove any CO_2 remaining in the biogas. The purified biogas stream **162** is delivered from the absorption riser **110** to the polishing tank **85** via a second inlet **31**. Within the polishing tank **85** a perforated pipe **88** may be used to distribute biogas **87** throughout the polishing tank **85**. Optionally, other distribution methods such as a nozzle or mixing element may be located within the polishing tank **85** to distribute the biogas **87**. The biogas **87** interacts with the calcium hydroxide, $Ca(OH)_2$, to remove CO_2 remaining in the biogas **87**. The calcium hydroxide, $Ca(OH)_2$, interacts with the carbon dioxide (CO_2) to generate calcium carbonate, $CaCO_3$, and water, H_2O, forming a slurry **89** that settles to the bottom of the polishing tank **85**. Further refined biogas **87** rises to the top of the polishing tank **85** and exits via an outlet **33** to storage or to a dryer **27**, if present.

[0085] In FIG. **26**, the polishing process **28** uses a solid polishing agent **92**. Similar to the liquid polishing agent **82**, the solid polishing agent is a hydroxide compound such as calcium hydroxide, sodium hydroxide, magnesium hydroxide, or potassium hydroxide. For purposes of discussion calcium hydroxide will again be discussed as the solid polishing agent **92**, however, this is not intended to be limiting. A cannister **90** is provided in which the solid polishing agent **92** is located. It is contemplated that the cannister **90** and solid polishing agent **92** may be provided in combination as a replaceable unit, where the cannister **90** is changed out after a predefined volume of biogas **87** has passed through the cannister **90**. Optionally, the cannister **90** may be a fixture in the treatment system and the solid polishing agent **92** may be removed and replaced within the cannister **90** after a predefined volume of biogas **87** has passed through the cannister **90**. The purified biogas stream **162** is delivered from the absorption risers **110** to an inlet **31** on the cannister **90**. Within the cannister **90** a perforated pipe **88** may be used to distribute biogas **87** throughout the cannister **90**. Optionally, other distribution methods such as a nozzle or mixing element may be located within the canister **90** to distribute the biogas **87**. The calcium hydroxide **92** is provided in a granular form, allowing the biogas **87** to flow through the solid polishing agent **92**. In a manner similar to that discussed above with the liquid polishing agent **82**, the biogas **87** interacts with the solid polishing agent **92**, calcium hydroxide $Ca(OH)_2$, to remove CO_2 remaining in the biogas **87**. The calcium hydroxide, $Ca(OH)_2$, interacts with the carbon dioxide (CO_2) in the biogas **87** to generate calcium carbonate, $CaCO_3$, and water, H_2O, forming a slurry **89** that falls to the bottom of the cannister **90**.

[0086] After a predefined volume of biogas **87** has passed through the cannister **90**, the ability of the calcium hydroxide to further react with the CO_2 in the biogas **87** will be depleted and the slurry in the cannister **90** will need to be cleaned out. As previously indicated, the cannister **90** and solid polishing agent **92** may be provided as a unit and the depleted cannister **90** with the slurry may be removed and a new cannister **90** and solid polishing agent **92** may be inserted. Optionally, the cannister **90** may have one or more openings by which the slurry may be removed and new solid polishing agent **92** introduced into the cannister **90** for further polishing of the purified biogas stream **162**.

[0087] With the biogas treatment process **510** integrated into a liquid absorbent treatment system **500**, the mixed liquid absorbent stream **166** from the last riser **100** in series connected risers or from each riser **100** in parallel connected risers, provides the source of the liquid carbon dioxide stream **518** for controlling the pH level of the disinfection process **520**. The mixed liquid absorbent stream **166** may be supplied directly or first be discharged into a holding tank or other such liquid holding feature for subsequent discharge. An excess volume of the mixed liquid absorbent stream water **166**, beyond that required for control of the pH level, may be discharged and the carbon dioxide allowed to dissipate naturally or to be aerated to facilitate the release of excess carbon dioxide.

[0088] In other applications, however, it may be desirable to include a recycling stage and reuse the liquid absorbent in which the carbon dioxide was dissolved. The wash system may then include a flash process **200**, an air stripper process **300**, a heating process, a gas-liquid membrane contactor, any other suitable process for separating the liquid absorbent and the carbon dioxide, or a combination thereof. According to the illustrated embodiment in FIG. **6**, both a flash process **200** and an air stripper process **300** are included. The mixed liquid absorbent stream **166** from the final absorption riser **110** is provided as an input to a flash riser **210** in the flash process **200**. As will be discussed in more detail below, the flash riser **210** separates residual methane dissolved in the mixed liquid absorbent stream **166**. The first outlet **260** is connected back to the initial processing stage **12** such that the methane extracted from the mixed liquid absorbent stream **166** may be recovered in subsequent processing and a liquid carbon dioxide stream is output from a second outlet **265** of the flash riser **210** to a second inlet **340** of an air stripping riser **310** in the carbon dioxide stripper process **300**. A fan **75** discharges air into the first inlet **345** of the air stripping riser **310**. As will be discussed in more detail below, the air stripping riser **310** separates the carbon dioxide from the liquid absorbent stream and the carbon dioxide is output from a first outlet **360**. The reclaimed liquid absorbent may be used again within the wash system and is pumped from the second outlet **365** of the air stripping riser **310** back to the holding tank **40**.

[0089] Optionally, when the biogas treatment system **510** is integrated into the water treatment system **500** as shown in FIGS. **1-4**, a flash process **200** may be provided to recover methane that may escape the absorber process **100** further purifying the mixed water stream **166** before it is used as the carbon dioxide water stream **518**. A valve **590** regulated by the controller **570** may be used to divert a portion of the carbon dioxide water stream **518** to the stripper process **300**, also shown as carbon dioxide aeration in FIG. **4**. Excess carbon dioxide which is not required for regulating the pH level in the disinfection process **520** may be directed to the stripping riser **310** and separated from the water stream.

[0090] Referring again to FIGS. **6** and **7**, each of the illustrated systems includes both a flash riser **210** and an air stripper riser **310**. With reference also to FIG. **12**, an exemplary flash riser **210** is illustrated. During the absorption process, a small amount of methane may be absorbed into the water stream. This methane is referred to herein as the “slip gas.” The flash riser **210** is configured to remove the slip gas from the mixed water stream **166** and return this methane to the supply for subsequent processing. The remaining water stream is passed on to the air stripping riser **310** where the carbon dioxide may be removed and the water reclaimed for subsequent use.

[0091] Each flash riser **210** includes multiple pipes. In the illustrated embodiment, the flash riser **210** includes an outer pipe **212**, a first inner pipe **222**, and a second inner pipe **232**. According to the illustrated embodiment, each of the pipes is concentric to the others. Optionally, the first inner pipe **222** and the second inner pipe **232** may be positioned adjacent to each other or extend downward at different locations within the outer pipe **212**. The outer pipe **212** has a first end **214**, a second end **216**, and a first length, L**1**. The first inner pipe **222** has a first end **224**, a second end **226**, and a second length, L**2**. The second inner pipe **232** has a first end **234**, a second end **236**, and a third length, L**3**. According to one embodiment of the invention, each of the flash risers **210** are installed in a vertical orientation, such that the first ends **214**, **224**, **234** of each pipe **212**, **222**, **232** are generally positioned at the top of each flash riser **210**. The first inner pipe **222** extends for the second length, L**2** into the outer pipe **212** and the mixed water stream **166** is delivered into the flash riser **210**. According to the illustrated embodiment, the first inner pipe **222** is cylindrical and open at the second end **226**. The mixed water stream **166** flows from the first inlet **250** and exits at the second end **226** of the first inner piper **222** The second inner pipe **232** extends for the third length, L**3**, through the first inner piper **222**, beyond the second end **226** of the first inner pipe **222**, and into the outer pipe **212**. The second inner pipe **232** is cylindrical and the second end **236** of the second inner pipe **232** includes a check valve between the interior of the outer pipe **212** and the interior of the second inner pipe **232**.

[0092] Each flash riser **210** includes an inlet and outlets to allow water and gas to flow into and out of the riser **210**. A first inlet **250** receives the mixed water stream **166** and is located on the first end **214** of the outer pipe **212**. The first inlet **250** is in fluid communication with the first end **224** of the

first inner pipe **222** and establishes a flow path for the mixed water stream **166** into the flash riser **210**. The first inner pipe **222** extends into the flash riser **210** for the length, L**2**, of the inner pipe **222**. According to the illustrated embodiment, the second end **226** of the first inner pipe **222** terminates at a perforated coalescing disk **246** proximate the second end **216** of the first inner pipe **222**. The mixed water stream **166** is dispensed into the flash riser **210** at the second end **226** of the first inner pipe **222**. The pressure within the flash riser **210** is reduced such that the slip gas present in the mixed water stream **166** is desorbed and released within the outer pipe **212**. The remaining water stream, however, continues to hold the carbon dioxide previously absorbed from the compressed biogas stream **30**. The output water stream from the flash riser will be referred to herein as the CO.sub.2 water stream **266**.
[0093] A first outlet **260** located at the first end **214** of the outer pipe **212** provides a flow path **261** for the slip gas **262** (i.e., the methane removed from the mixed water stream **166**) to exit the flash riser **210**. The first outlet **260** is in fluid communication with and receives the slip gas **262** from the interior of the outer pipe **212**. A second outlet **265** is also located at the first end **214** of the outer pipe **212** and provides a flow path **267** for the CO.sub.2 water stream **266**. The second outlet **265** is in fluid communication with the first end **234** of the second inner pipe **232**. The CO.sub.2 water stream **266** enters the second end **236** of the second inner pipe **232** and travels up through the second inner pipe **232** to the second outlet **265**. According to the illustrated embodiment, each of the outer pipe **212**, first inner pipe **222**, and second inner pipe **232** are concentric about a central axis. The second inner pipe **232** is located within the first inner pipe **222**, which is, in turn, located within the outer pipe **212**. As discussed above and for purposes of illustration in FIG. **12**, the first end **214**, **224**, **234** of each pipe **212**, **222**, **232** ends at substantially the same point. It is contemplated that in various embodiments the first end **224**, **234** of each of the first inner pipe **222** and the second inner pipe **232** may extend for a short distance beyond the first end **214** of the outer pipe **212** to facilitate connections between each pipe and an inlet or outlet. It is further contemplated that an inlet **250** or outlet **260**, **265** may be positioned along and enter the outer pipe **212** via a side wall proximate the end of the flash riser **210**. For example, the first inlet **250** is shown connecting generally orthogonally to a wall of the first inner pipe **222** beyond the first end **212** of the outer pipe and the second inner pipe **232** extends through an end wall of the first inner pipe **222** to connect to the second outlet **265**. Alternately, the first inlet **250** or second outlet **265** may include a fixture connected to the first end **214** of the outer pipe **212** and comprise the necessary connections to establish the fluid flow paths from the inlet and outlet to the inner pipes extending into the outer pipe **212**.
[0094] According to the illustrated embodiments in FIGS. **6-9**, the carbon dioxide water stream **518** is shown being connected to the second outlet **265** of the flash riser **210**. If a system does not include a flash riser, the carbon dioxide water stream **518** may be connected to the second outlet **165** of the absorption riser(s) **110**.
[0095] Each air stripping riser **310** also includes multiple pipes. In the illustrated embodiment, the air stripping riser **310** includes an outer pipe **312**, a first inner pipe **322**, and a second inner pipe **332**. According to the illustrated embodiment, each of the pipes is concentric to the others. Optionally, the first inner pipe **322** and the second inner pipe **332** may be positioned adjacent to each other or extend downward at different locations within the outer pipe **312**. The outer pipe **312** has a first end **314** and a second end **316**. The first inner pipe **322** has a first end **324** and a second end **326**. The second inner pipe **332** has a first end **334** and a second end **336**. According to one embodiment of the invention, each of the air stripping riser **310** are installed in a vertical orientation, with the first end **314** of the outside pipe positioned at the top of the air stripping riser **310**. The first ends **324**, **334** of each inner pipe **322**, **332** are generally positioned at a flange **311** located within the air stripping riser **310**. When the air stripping riser **310** is used in conjunction with the absorption risers **110** and/or the flash riser **210**, it is contemplated that the flange **311** on the air stripping riser **310** is located at the same height as the first end of the absorption riser **110**

and/or flash riser **210**. The first inner pipe **322** extends downward for a length into the outer pipe **312**. The first inner pipe **322** receives an air flow **70** from a fan **75** at a first inlet **345** and delivers the air flow **70** proximate the bottom of the air stripping riser **310** but above a level at which water may be present in the bottom of the air stripping riser **310**. According to the illustrated embodiment, the first inner pipe **322** is cylindrical and open at the second end **326**. The air flow **70** is passed from the first inlet **345** and exits at the second end **326** of the first inner piper **322**. The second inner pipe **332** extends through the first inner piper **322**, beyond the second end **326** of the first inner pipe **322**, and into the outer pipe **312**. The second inner pipe **332** is cylindrical and the second end **336** of the second inner pipe **332** includes a check valve between the interior of the outer pipe **312** and the interior of the second inner pipe **332**.

[0096] Each air stripping riser **310** includes a set of inlets and outlets to allow water and gas to flow into and out of the riser **310**. A second inlet **340** of the air stripping riser **310** receives the CO.sub.2 water stream **266** from the flash riser **210**. Optionally, if no flash riser **210** present, the second inlet **340** of the air stripping riser **310** may receive the mixed water stream **166** output from the absorption risers **110**. The second inlet **340** is located proximate the top of the air stripping riser **310**. According to the illustrated embodiment, a first intermediate pipe **341** and a second intermediate pipe **342** each extend from the second inlet **340** into the air stripping riser **310**. The first intermediate pipe **341** extends upward and enters the air stripping riser **310** proximate the first end **314** of the outer pipe **312**. The second intermediate pipe **342** enters the air stripping riser **310** proximate the flange **311** and the first ends **324**, **334** of the first and second inner pipes **322**, **332**. The first intermediate pipe **341** is in fluid communication with a first nozzle **343** that sprays the CO.sub.2 water stream **266** into the top of the air stripping riser **310** and the second intermediate pipe **342** is in fluid communication with a second nozzle **344** that sprays the CO.sub.2 water stream **266** into the air stripping riser **310** at a midpoint along the air stripping riser **310**. The dual entry points for the CO.sub.2 water stream **266** define separate segments of the air stripping riser **310** that may then interact with the air flow **70** entering the air stripping riser **310** to remove the carbon dioxide from the CO.sub.2 water stream **266**.

[0097] As previously indicated, air flow **70** is provided at the first inlet **345** and into the first inner pipe **322**, establishing a flow path for the air flow **70** into the air stripping riser **310**. The first inner pipe **322** extends into the air stripping riser **310** for a length and, according to the illustrated embodiment, the second end **326** of the first inner pipe **322** terminates at a dispersion element **349** proximate the second end **316** of the first inner pipe **322**. The air flow **70** is dispensed into the air stripping riser **310** at the second end **326** of the first inner pipe **322** as illustrated by the air flow path **367**. The pressure within the air stripping riser **310** is further reduced from the flash riser **210** and is preferably maintained at or near atmospheric pressure. The reduction in pressure reduces the solubility of carbon dioxide in water facilitating the release of the carbon dioxide from the CO.sub.2 water stream **266** within the outer pipe **312**. The air flow **70** is pumped into the bottom of the air stripping riser **310** such that the air flow **70** rises counter to the CO.sub.2 water stream **266** being sprayed into the top of the riser **310**. The air flow **70** interacts with water droplets to facilitate release of the carbon dioxide and further carries the carbon dioxide toward the top of the air stripping riser **310**.

[0098] A first outlet **360** located at the first end **314** of the outer pipe **312** provides a flow path **361** for the carbon dioxide **362** removed from the CO.sub.2 water stream **266** to exit the air stripping riser **310**. The first outlet **360** is in fluid communication with and receives the carbon dioxide **362** from the interior of the outer pipe **312**. A second outlet **365** is located proximate the first end **324** of the second inner pipe **232**. As illustrated, the second inner pipe **332** is connected to a ninety degree bend pipe **337** and to a short outlet pipe **338** such that it extends out the side of the outer pipe **312**. The second outlet **365** provides a flow path **367** for the reclaimed water stream **366**. The second outlet **365** is in fluid communication with the first end **334** of the second inner pipe **332**. The reclaimed water stream **366** enters the second end **336** of the second inner pipe **332** and travels up through the second inner pipe **332** to the second outlet **365**. According to the illustrated embodiment, each of the outer pipe **312**, first inner pipe **322**, and second inner pipe **332** are concentric about a central axis. The second inner pipe **332** is located within the first inner pipe **322**, which is, in turn, located within the outer pipe **312**. The first end **324**, **334** of each inner pipe **322**, **332** ends proximate the flange **311** located within the outer pipe **312**. The first inlet **345** and the second outlet **365** are connected to the first inner pipe **322** and the second inner pipe **332**, respectively, and extend out through a wall of the outer pipe **312**. Although the first end **314** of the outer pipe **312** extends for some distance beyond the flange **311**, it is contemplated that in various embodiments the second inlet **340** may run directly into the outer pipe with a single intermediate pipe and the first end **314** of the outer pipe **312** may be positioned proximate the flange **311**. Optionally, the first end **224**, **234** of each of the first inner pipe **222** and the second inner pipe **232** may extend up to or for a short distance beyond the first end **314** of the outer pipe **312** without deviating from the scope of the invention.

[0099] It is further contemplated that each air stripping riser **310** may include packing material within at least a portion of the interior of the outer pipe **312** to further enhance the release of the carbon dioxide from the CO.sub.2 water stream **266**. In FIG. **13**, additional dispersion plates **349** are shown spaced apart within the outer pipe **312**. One or more additional dispersion plates may be distributed along the length of the interior of the outer pipe **312** to continually redistribute the air flow **70** and CO.sub.2 water stream **266** as they travel through the interior of the pipe. It is also contemplated that packing material similar to that used in the absorption riser **110** may be inserted into the air stripping riser **310**. With reference again to FIGS. **14** and **15**, a flexible, porous material **170** may be rolled into a coil and inserted between the inner periphery of the outer pipe and the outer periphery of the first inner pipe. According to one embodiment of the invention, the flexible material **170** is a netting material, such as a geonet, including multiple holes throughout the material. As the CO.sub.2 water stream **266** passes through the air stripping riser **310**, the netting and the multiple holes create numerous flow paths and opportunities for separating the CO.sub.2 water stream **266** into more droplets and, thereby, increasing the surface area of the water stream exposed to the air, facilitating release of the carbon dioxide into the air. In FIG. **15**, a mesh material **180** may be formed into a basket or bag and is used to contain another bulk material **182** within the mesh. The mesh and bulk materials **180**, **182** may be inserted into and removed from the interior of the outer pipe as a unit. Both the flexible material **170** and the mesh and bulk material combination **180**, **182** facilitate cleaning of the packing material. The flexible material **170** may be removed and unrolled for cleaning. The mesh and bulk material **180**, **182** may be pulled out of the outer pipe and the bulk material spread out for cleaning. Once clean, the flexible material **170** may be rolled back into a coil and inserted back into the outer pipe. Similarly, the bulk material **182** may be placed back into the mesh material **180** and inserted into the outer pipe.

[0100] According to still another embodiment of the invention, the diameter and/or length of an absorption riser **110** may make the insertion of a material within the absorption riser challenging. Therefore, it is contemplated that the packing material may be a porous structure or material that is poured, blown, or pumped into the absorption riser **110**. Initially, a mesh filter or grate may be inserted at a particular depth or length within the absorption riser to prevent the porous structure or material from passing beyond a certain point within the absorption riser **110**. The filter or grate has openings of a smaller size than the size of individual members of the packing material, such that the packing material is stopped by the filter or grate while allowing the biogas and water streams flow through and around the packing material and filter or grate. It is further contemplated that the filter or grate may be connected to a cable or rod to facilitate cleaning or maintenance on the absorption riser. The cable or rod may have mixing devices attached or it may be used to pull the filter or grate out of the absorption riser **110** which, in turn, would pull out the packing material, allowing the packing material and/or the interior of the absorption riser to be inspected or maintained.

[0101] The carbon dioxide **362** extracted from the CO.sub.2 water stream **266** in the air stripping riser **310** may be vented directly from the first outlet **360** into the atmosphere. However, the potential exists that the carbon dioxide **362** stream may also include other contaminants. Therefore, it may be desirable to discharge the carbon dioxide **362** into the environment in another manner such that further processing may be performed on the carbon dioxide stream **362**. Referring next to FIGS. **17-19**, three exemplary off-gas discharge methods are illustrated. In FIG. **17**, the carbon dioxide **362** is carried through a discharge pipe **400** into a bio-filter material **405**. The bio-filter material is mounded above the ground **410** and the discharge pipe **400** is perforated along the length extending into the bio-filter material. The carbon dioxide **362** is vented into the bio-filter material as shown by the arrows **420**. In FIG. **18**, the carbon dioxide **362** is carried through a discharge pipe **400** for some distance above the ground **410** and is then buried below the ground **410**. The discharge pipe **400** is perforated along the length extending below the ground, and the carbon dioxide **362** is vented into the ground as shown by the arrows **420**. In FIG. **19**, the carbon dioxide **362** is carried through a discharge pipe **400** into a water reservoir **415** formed in the ground **410**. The water reservoir **415** may be naturally occurring such as a pond or lake or may be constructed by digging an area dug out of the ground **410**. The discharge pipe **400** is perforated along the length extending under the water, and the carbon dioxide **362** is vented into the water reservoir as shown by the arrows **420**. According to still another embodiment of the invention, it may be desirable to provide a thermal oxidization unit and the carbon dioxide **362** and other trace constituents may pass through the thermal oxidization unit prior to release into the atmosphere. Any of the exemplary off-gas discharge methods may be utilized to regulate a level of carbon dioxide available for adjusting the pH level of the disinfection process **520**. The controller **570** receives inputs from sensors corresponding to operating conditions within the water treatment process, such as pressure, temperature, pH levels, flow rates, and the like and supplies the appropriate carbon dioxide water stream **518** to achieve a desired pH level in the second basin **540**.
[0102] Referring next to FIGS. **8** and **9**, an exemplary biogas treatment system incorporating another embodiment of the present invention is illustrated. As discussed above with respect to FIG. **6**, a biogas stream **10** is provided as an input to the system, where the biogas may be produced, for example, from an anaerobic decomposition process. Some initial processing of the biogas stream may occur prior to supplying the biogas stream to the water wash system. An optional hydrogen sulfide removal process **15** such as an iron sponge type system may be inserted in series with the biogas stream **10** to perform an initial removal of hydrogen sulfide present in the biogas stream. The biogas stream may also be passed through a filter **20** to remove particulate content. In addition, carbon dioxide has increased solubility characteristics with decreasing temperature and increasing pressure. The biogas stream is, therefore, passed through a compressor **25** to achieve an elevated pressure. The pressure range of the compressed biogas stream **30** may be between forty and two hundred pounds per square inch gauge (40-200 psig). According to one embodiment of the invention, the pressure range of the compressed gas is between about one hundred and one hundred fifty pounds per square inch gauge (100-150 psig). The compressed biogas may also be chilled, for example, to between thirty-five and sixty-eight degrees Fahrenheit (35-68° F.). The compressed and/or chilled biogas stream **30** is provided as an input to the water wash process.
[0103] Similar to the embodiment illustrated in FIGS. **6** and **7**, the water wash process illustrated in FIG. **8** utilizes water to remove the carbon dioxide from the biogas stream. In the embodiments illustrated in FIGS. **6** and **7**, however, the water and biogas streams flow in opposite directions (i.e., counter-current) to each other through the absorption risers **110**. In the embodiments illustrated in FIGS. **8** and **9**, the water and biogas streams flow in the same direction (i.e. concurrent) to each other through an absorption riser **110**. According to the illustrated embodiment, water is provided to a holding tank **40** from which a water stream **50** is provided to the water wash process. Water provided to the holding tank **40** may be chilled and/or under pressure to facilitate the water wash process. Optionally, the holding tank **40** may incorporate a chiller and/or a compressor to chill or

pressurize the water prior to supplying it in the water stream. The water, for example, may be chilled to between thirty-five and sixty-eight degrees Fahrenheit (35-68° F.) and pressurized to mix with the compressed biogas stream **30** at about the same input pressure of the biogas stream.

[0104] In the biogas treatment system of FIG. **8**, a single absorption riser **110** is provided. Referring also to FIG. **23**, the absorption riser **110** includes multiple pipes. In the illustrated embodiment, the absorption riser **110** includes an outer pipe **112**, a first inner pipe **122**, and a second inner pipe **132**. According to the illustrated embodiment, each of the inner pipes **122**, **132** is concentric to the outer pipe **112**. Optionally, the inner pipes **122**, **132** may be positioned at different locations (e.g., along the interior wall) within the outer pipe **112**. The outer pipe **112** has a first end **114** and a second end **116**. The first inner pipe **122** has a first end **124** and a second end **126**. The second inner pipe **132** has a first end **134** and a second end **136**. The outer pipe **112** also includes a first segment **117**, a second segment **118**, and a third segment **119**. It is contemplated that the absorption riser **110** may be buried within the ground or submerged below water. Optionally, the outer pipe **112** and the inner pipes may be formed of a flexible material and may extend in one or more rows or be coiled up and placed, for example, on the ground in a substantially horizontal configuration.

[0105] If the pipes are buried or submerged, the first segment **117** extends downward where the first end **114** of the outer pipe **112** may be located at a surface level. The first inner pipe **122** is located within the first segment **117**, where the first end **124** of the first inner pipe **122** is generally positioned at the first end **114** of the outer pipe **112**. The second segment **118** extends generally in a horizontal direction, and the first inner pipe **122** also includes a horizontal segment **128** that extends, at least for a portion of the horizontal direction, within the outer pipe **112**. The horizontal segment **128** includes a plurality of perforations **127** located along the length of the horizontal segment **128** from which the compressed biogas stream **30** may be released into the water flowing through the outer pipe. It is contemplated that the perforations **127** may also be located along the descending portion of the inner pipe **122** within the first segment **117** of the outer pipe **112**. The third segment **119** extends upward back to the surface level. The second inner pipe **132** is located within the third segment **119** of the outer pipe **112**. The second inner pipe **132** is cylindrical and the second end **136** of the second inner pipe **132** is located proximate the transition between the second segment **118** and the third segment **119** of the outer pipe **112**. The first end **134** of the second inner pipe **132** is located proximate the second end of the outer pipe. The second end **136** of the second inner pipe **132** includes a check valve between the interior of the outer pipe **112** and the interior of the second inner pipe **132**, where the check valve is controlled to allow the mixed water stream to enter the second inner pipe **132** and be drawn up and out of the absorption riser **110** through the second inner pipe.

[0106] If the pipes are laid out in rows or coiled up and placed on the ground, the first segment **117** extends for a portion of the absorption riser **110** and the first end **114** of the outer pipe **112** is located at a first end of the absorption riser **110**. The first inner pipe **122** is located within the first segment **117**, where the first end **124** of the first inner pipe **122** is generally positioned at the first end **114** of the outer pipe **112**. The second segment **118** extends for a second portion of the absorption riser **110**, and the first inner pipe **122** also extends at least for a portion of the second segment **118**. The first inner pipe **122** includes a plurality of perforations **127** located along the length of the first inner pipe within the second segment **118** from which the compressed biogas stream **30** may be released into the water flowing through the outer pipe **112**. The third segment **119** extends for a third portion of the outer pipe **112**, and the second inner pipe **132** is located within the third segment **119** of the outer pipe **112**. The second inner pipe **132** is cylindrical and the second end **136** of the second inner pipe **132** is located proximate the transition between the second segment **118** and the third segment **119** of the outer pipe **112**. The first end **134** of the second inner pipe **132** is located proximate the second end of the outer pipe. The second end **136** of the second inner pipe **132** includes a check valve between the interior of the outer pipe **112** and the interior of the second inner pipe **132**, where the check valve allows the mixed water stream to flow in one direction to enter the second inner pipe **132** and be drawn up and out of the absorption riser **110** through the second inner pipe.

[0107] In the biogas treatment system of FIG. **9**, the single absorption riser **110** of FIG. **8** may be divided into two portions, where a first portion **111** includes the first segment **117** and the second segment **118** of the absorption riser **110** as discussed above with respect to FIG. **8**. The second portion **113** includes the third segment **119** of the absorption riser **110** as discussed above with respect to FIG. **8**. Referring also to FIG. **22**, the absorption riser **110** includes multiple pipes. In the illustrated embodiment, the absorption riser **110** includes an outer pipe **112**, a first inner pipe **122**, and a second inner pipe **132**. According to the illustrated embodiment, each of the inner pipes **122**, **132** is concentric to the outer pipe **112**. Optionally, the inner pipes **122**, **132** may be positioned at different locations (e.g., along the interior wall) within the outer pipe **112**. The outer pipe **112** is divided into two lengths, where the first length **112**A of the outer pipe has a first end **114**A and a second end **116**B. The outer pipe **112** also includes a first segment **117** and a second segment **118** extending within the first length **112**A of the outer pipe **112**. A third segment **119** extends for the second length **112**B of the outer pipe **112**. The first inner pipe **122** has a first end **124** and a second end **126**, where the first end **124** is proximate the first end **114**A of the first length **112**A of the outer pipe. It is contemplated that the absorption riser **110** may be buried within the ground or submerged below water. Optionally, the outer pipe **112** and the inner pipes may be formed of a flexible material and may extend in one or more rows or be coiled up and placed, for example, on the ground in a substantially horizontal configuration.

[0108] If the pipes are buried or submerged, the first segment **117** extends downward where the first end **114**A of the first length **112**A of the outer pipe **112** may be located at a surface level. The first inner pipe **122** is located within the first segment **117**, where the first end **124** of the first inner pipe **122** is generally positioned at the first end **114**A of the first length **112**A of the outer pipe **112**. The second segment **118** extends generally in a horizontal direction, and the first inner pipe **122** also includes a horizontal segment **128** that extends, at least for a portion of the horizontal direction, within the outer pipe **112**. The horizontal segment **128** includes a plurality of perforations **127** located along the length of the horizontal segment **128** from which the compressed biogas stream **30** may be released into the water flowing through the outer pipe. It is contemplated that the perforations **127** may also be located along the descending portion of the inner pipe **122** within the first segment **117** of the outer pipe **112**. Optionally, a series of nozzles or other gas injectors may be located along the length of the inner pipe **122**, where each nozzle disperses a portion of the biogas stream within the outer pipe **112**. According to still another option, multiple inner pipes **122** may be provided, where each inner pipe **122** includes a series of perforations **127** or nozzles spaced along the length of each inner pipe **122** to facilitate dispersion of the biogas stream **30** throughout the interior of the outer pipe **112**. The second segment **118** may further include a rising section, where at least the first length **112**A of the outer pipe and, optionally, the inner pipe **122** extend for a distance back toward the surface level.

[0109] If the pipes are laid out in rows or coiled up and placed on the ground, the first segment **117** extends for a portion of the absorption riser **110** and the first end **114**A of the outer pipe **112** is located at a first end of the absorption riser **110**. The first inner pipe **122** is located within the first segment **117**, where the first end **124** of the first inner pipe **122** is generally positioned at the first end **114** of the outer pipe **112**. The second segment **118** extends for a second portion of the absorption riser **110**, and the first inner pipe **122** also extends at least for a portion of the second segment **118**. The first inner pipe **122** includes a plurality of perforations **127** located along the length of the first inner pipe within the second segment **118** from which the compressed biogas stream **30** may be released into the water flowing through the outer pipe **112**. It is contemplated that the perforations **127** may also be located along the portion of the inner pipe **122** within the first segment **117** of the outer pipe **112**. The third segment **119** extends for a third portion of the outer pipe **112**, and the second inner pipe **132** is located within the third segment **119** of the outer pipe

112. According to one embodiment, the first and second segments **117**, **118** defining the first length **112**A of the outer pipe **112** may be located generally horizontally, for example, on the ground and the second length **112**B of the outer pipe **112** may extend vertically, for example, buried or submerged below a surface level of ground or water.

[0110] The second length **112**B of the outer pipe **112** defines a substantially vertical pipe having a first end **114**B and a second end **116**B. The second end **116**A of the first length **112**A of the outer pipe is connected proximate the first end **114**B of the second length **112**B of the outer pipe. The second inner pipe **132** is located within the third segment **119** of the outer pipe **112**, which corresponds to the second length **112**B of the outer pipe. The second inner pipe **132** has a first end **134** and a second end **136**. The second inner pipe **132** is cylindrical and the second end **136** of the second inner pipe **132** is located proximate the second end **116**B of the second length **112**B of the outer pipe. The first end **134** of the second inner pipe **132** is located proximate the first end **114**B of the second length **112**B of the outer pipe. The second end **136** of the second inner pipe **132** includes a check valve between the interior of the second length **112**B of the outer pipe **112** and the interior of the second inner pipe **132**, where the check valve allows the mixed water stream to flow in one direction to enter the second inner pipe **132** and be drawn up and out of the absorption riser **110** through the second inner pipe.

[0111] With reference again to FIGS. **8-9** and **20-22**, the absorption riser **110** includes a set of inlets and outlets to allow water and biogas to flow into and out of the riser **110**. A first inlet **140** receives the compressed biogas stream **30** and is located on the first end **114** of the outer pipe **112**. The first inlet **140** is in fluid communication with the first end **124** of the first inner pipe **122** and establishes a flow path for the compressed biogas stream **30** into the absorption riser **110**. As previously indicated, the first inner pipe **122** extends into through the first segment **117** and into the second segment **118** of the outer pipe **112**, and the second end **126** of the first inner pipe **122**. A second inlet **145** receives the water stream **50** and is located on the first end **114** of the outer pipe **112**. The second inlet **145** is in fluid communication with the first end **114** of the outer pipe **112** to dispense the water stream **50** from the first end of the absorption riser **110**. The water stream **50** flows through to the second end of the absorption riser. The compressed biogas stream **30** is dispensed into the water flow from the perforations **127** in the first inner pipe **122** and flows toward the second end of the absorption riser.

[0112] As the compressed biogas stream **30** and the water stream **50** flow along the horizontal portion of the absorption riser **110** the two streams mix and the carbon dioxide within the compressed biogas stream **30** is dissolved into the water. Although small amounts of methane may be absorbed in the water, the majority of the methane remains unabsorbed. The methane is lighter than the mixed water stream containing carbon dioxide. With reference to FIGS. **8** and **20**, the methane rises to the second end **116** of the absorption riser **110**. The mixed water stream **166** including the carbon dioxide absorbed from the biogas stream is heavier than the methane and remains at the end of the horizontal segment of the absorption riser at the transition to the upward segment. A first outlet **160** located at the second end **116** of the outer pipe **112** provides a flow path **161** for the purified biogas stream **162** to exit the absorption riser **110**. The first outlet **160** is in fluid communication with and receives the purified biogas stream **162** from the interior of the outer pipe **112**. With reference to FIGS. **9** and **22**, the flow in the first length **112**A of the outer pipe created by the water stream **50** and the biogas stream **30** establish a flow through the first length **112**A of the outer pipe **112** and into the second length **112**B of the outer pipe. The mixed water stream then falls to the second end **116**B of the second length **112**B of the outer pipe and the methane rises to the first end **114**B of the second length **112**B of the outer pipe. A first outlet **160** located at the first end **114**B of the second length **112**B of the outer pipe **112** provides a flow path **161** for the purified biogas stream **162** to exit the absorption riser **110**. The first outlet **160** is in fluid communication with and receives the purified biogas stream **162** from the interior of the outer pipe **112**. A second outlet **165** is also located proximate the first outlet **160** and provides a flow path

167 for the mixed water stream **166**. The second outlet **165** is in fluid communication with the first end **134** of the second inner pipe **132**. The mixed water stream **166** enters the second end **136** of the second inner pipe **132** and travels up through the second inner pipe **132** to the second outlet **165**. As discussed above and for purposes of illustration in FIG. **9**, the first ends **114**, **124**, of the outer pipe **112** and the first inner pipe **122** end at substantially the same point. Similarly, the first end **134** of the second inner pipe **132** and the second end **116** of the outer pipe **112** end at substantially the same point. It is contemplated that in various embodiments the first end **124**, **134** of each of the first inner pipe **122** and the second inner pipe **132** may extend for a short distance beyond either end of the outer pipe **112** to facilitate connections between each pipe and an inlet or outlet.

[0113] Because the interaction of the water stream and the biogas stream is reduced when the streams are travelling in the same direction rather than travelling in opposite directions, transfer of carbon dioxide from the compressed biogas stream **30** to the water stream **50** occurs at a reduced rate per length of travel. Thus, the embodiment illustrated in FIG. **8** is better suited for applications in which a lengthy horizontal segment of the absorption riser is available. It is contemplated that each pipe of the absorption riser may be formed of a flexible material and coiled or laid out in rows alternating back and forth adjacent to each other. According to one embodiment, the absorption riser may extend along the ground in a generally horizontal orientation. According to another embodiment, the absorption riser **110** may be routed into a pond, lake, or other available water source. The water may provide some protection and/or insulation for the absorption riser **110**. The absorption riser may extend in numerous configurations, such as a straight line, a curved path, an alternating back-and-forth route, or a combination thereof to increase the length of the horizontal segment. It is contemplated that the horizontal segment of the absorption riser **110** may extend for one hundred feet or longer before the absorption riser **110** transitions to the upward segment. Optionally, a portion, or all, of the absorption riser may include an external sleeve to provide further protection and/or insulation. The sleeve may further provide weight to the absorption riser **110** if it is installed in an underwater application to reduce buoyancy and to help keep the absorption riser **110** along the bottom of the pond, lake, or other water source.

[0114] To increase the interaction between the water stream **50** and the biogas stream **30**, it is contemplated that one or more mixing elements may be included along the length of travel. The mixing elements may be powered, for example, a rotating member within the pipe, or preferably, may be passive mixing elements. The passive mixing elements are configured to disrupt a linear flow path through the pipes, causing the water stream **50** and the biogas stream **30** to intermix their flows along the length of the absorption riser. With reference to FIGS. **20** and **22**, it is contemplated that a dispersion plate **149** may be included within the outer pipe **112**. The dispersion plate may be located proximate the inlets to disperse a flow across the interior of the absorption riser **110**. Optionally, one or more dispersion plates **149** may be located beyond the second end **126** of the first inner pipe **122** to encourage mingling of the two flows. With reference also to FIGS. **23** and **24**, the interior of the absorption riser **110** may have different configurations. In FIG. **23**, the horizontal segment **128** of the inner pipe is illustrated with perforations **127** distributed around the pipe. The compressed biogas stream **30** escapes through the perforations **127** into the water stream **50** flowing in the same direction through the pipe. Optionally, and as shown in FIGS. **22** and **24**, the horizontal segment **118** of the outer pipe **112** may include packing material **190** within at least a portion of the interior of the horizontal segment **118** to further enhance the release of the carbon dioxide from the water stream **50**. The compressed biogas stream **30** may be discharged into the horizontal segment **118** in advance of the packing material **190** so that the compressed biogas stream **30** and the water stream **50** travel through the packing material **190** and, thereby increase contact between the two streams. A partially mixed stream **55** is illustrated as continuing on along the horizontal segment of the absorption riser **110**. It is further contemplated that a combination of the two embodiments may be utilized in which the horizontal segment **128** of the inner pipe extends into a segment of the outer pipe **112** that has packing material **190** located therein.

[0115] It should be understood that the invention is not limited in its application to the details of construction and arrangements of the components set forth herein. The invention is capable of other embodiments and of being practiced or carried out in various ways. Variations and modifications of the foregoing are within the scope of the present invention. It also being understood that the invention disclosed and defined herein extends to all alternative combinations of two or more of the individual features mentioned or evident from the text and/or drawings. All of these different combinations constitute various alternative aspects of the present invention. The embodiments described herein explain the best modes known for practicing the invention and will enable others skilled in the art to utilize the invention.

Claims

1. A system for separating carbon dioxide from a biogas stream, the system comprising: a first pipe having a first end and a second end; a second pipe extending within the first pipe, the second pipe having a first end and a second end, wherein the first end of the second pipe is proximate the first end of the first pipe; a first inlet at the first end of the second pipe to deliver the biogas stream into the second pipe; a second inlet at the first end of the first pipe to deliver a liquid absorbent into the first pipe, wherein: the biogas stream is dispensed from the second pipe to an interior of the first pipe, and the biogas stream mixes with the liquid absorbent within the first pipe to separate the carbon dioxide from the biogas stream resulting in a purified biogas stream and a mixed liquid absorbent stream; a first outlet in fluid communication with the first pipe to deliver the purified biogas stream from the first pipe; a third pipe extending into the first pipe, the third pipe having a first end and a second end, wherein the first end of the third pipe extends from the first pipe and the second end of the third pipe extends into the mixed liquid absorbent stream within the first pipe; and a second outlet in fluid communication with the first end of the third pipe to deliver the mixed liquid absorbent stream.
2. The system of claim 1, further comprising a removable packing material inserted within the first pipe, wherein the removable packing material causes the biogas stream to mix with the liquid absorbent.
3. The system of claim 2, wherein the removable packing material is selected from one of a netting material rolled into a coil and a bulk material contained within a mesh material.
4. The system of claim 1, further comprising at least one mixing element mounted within the first pipe to distribute the biogas stream and the liquid absorbent within the interior of the first pipe.
5. The system of claim 1, wherein at least a portion of the first pipe extends in a generally horizontal direction.
6. The system of claim 1, wherein: at least a portion of the second pipe extends for a distance within the first pipe; and an outer periphery of the second pipe includes a plurality of holes to dispense the biogas stream from the second pipe to the interior of the first pipe.
7. The system of claim 1, wherein the liquid absorbent is selected from one of water, hydroxides, carbonates, ammonia, amines, amino acids, propylene carbonate, ethylene glycol, polyethylene glycol, methanol, and alcohol.
8. The system of claim 1, further comprising a riser mounted to the second end of the first pipe, wherein: the first outlet is an inlet to the riser, the inlet to the riser is further configured to receive the mixed liquid absorbent stream from the first pipe, the riser separates the purified biogas stream from the mixed liquid absorbent stream, the first end of the third pipe extends from a first end of the riser, the second outlet delivers the mixed liquid absorbent stream through the first end of the riser via the third pipe, and the riser includes a third outlet at the first end of the riser to deliver the purified biogas stream.
9. The system of claim 1, further comprising a recycling stage, wherein the recycling stage has an inlet in fluid communication with the second outlet to receive the mixed liquid absorbent stream

and wherein the recycling stage is configured to separate the carbon dioxide from the mixed liquid absorbent stream.

10. The system of claim 9, wherein the recycling state further comprises: a first outlet configured to deliver the carbon dioxide; and a second outlet in communication with the second inlet at the end of the first pipe to return the liquid absorbent into the first pipe.

11. A method for separating carbon dioxide from a biogas stream, the method comprising the steps of: supplying a liquid absorbent to a first inlet in fluid communication with a first pipe; supplying the biogas stream to a second inlet in fluid communication with a second pipe, wherein: the first pipe has a first end and a second end, the second pipe has a first end and a second end, the first end of the second pipe is proximate the first end of the first pipe, the first inlet is at the first end of the first pipe, and the second inlet is at the first end of the second pipe; delivering the biogas stream from the second pipe into first pipe; mixing the biogas stream with the liquid absorbent within the first pipe to separate the carbon dioxide from the biogas stream resulting in a purified biogas stream rising to a top of the first pipe and a mixed liquid absorbent stream flowing to a bottom of the first pipe; dispensing the purified biogas from a first outlet located at the second end of the first pipe; and dispensing the mixed liquid absorbent stream from a second outlet located at the second end of the first pipe, wherein the mixed liquid absorbent is drawn through a third pipe, which extends into the first pipe and to the second outlet.

12. The method of claim 11, wherein the step of mixing the biogas stream with the liquid absorbent further comprises passing the liquid absorbent and the biogas stream through a removable packing material inserted within the first pipe.

13. The method of claim 12, wherein the removable packing material is selected from one of a netting material rolled into a coil and a bulk material contained within a mesh material.

14. The method of claim 11, wherein the step of mixing the biogas stream with the liquid absorbent further comprises passing the liquid absorbent and the biogas stream through at least one mixing element mounted within the first pipe.

15. The method of claim 11, wherein at least a portion of the first pipe extends in a generally horizontal direction.

16. The method of claim 11, wherein: at least a portion of the second pipe extends for a distance within the first pipe; and the step of delivering the biogas stream from the second pipe into first pipe further comprises dispensing the biogas stream from a plurality of holes in an outer periphery of the second pipe.

17. The method of claim 11, wherein the liquid absorbent is selected from one of water, hydroxides, carbonates, ammonia, amines, amino acids, propylene carbonate, ethylene glycol, polyethylene glycol, methanol, and alcohol.

18. The method of claim 11, further comprising a riser mounted to the second end of the first pipe, wherein: the first outlet is an inlet to the riser, the inlet to the riser is further configured to receive the mixed liquid absorbent stream from the first pipe, and the first end of the third pipe extends from a first end of the riser, the method further comprising the steps of: separating the purified biogas stream from the mixed liquid absorbent stream in the riser; delivering the mixed liquid absorbent stream to the second outlet through the first end of the riser via the third pipe, and dispensing the purified biogas stream from a third outlet located at the first end of the riser.

19. The method of claim 11, further comprising the steps of: delivering the mixed liquid absorbent stream from the second outlet to a recycling stage; and separating the carbon dioxide from the mixed liquid absorbent stream in the recycling stage.

20. The method of claim 19, further comprising the step of delivering the liquid absorbent, resulting from separating the carbon dioxide from the mixed liquid absorbent, from the recycling stage to the second inlet at the end of the first pipe.