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(71) Applicants: **WONG FONG ENGINEERING WORKS (1988) PTE LTD** [SG/SG]; 79 Joo Koon Circle, Singapore 629107 (SG). **NATIONAL UNIVERSITY OF SINGAPORE** [SG/SG]; 21 Lower Kent Ridge Road, Singapore 119077 (SG). **SHANGHAI JIAO TONG UNIVERSITY** [CN/CN]; 800 Dongchuan Road, Shanghai 200240 (CN).

(72) Inventors: **BAN, Yinh Jheow**; 79 Joo Koon Circle, Singapore 629107 (SG). **ANG, Seong We, Jack**; 79 Joo Koon Circle, Singapore 629107 (SG). **MEMOLA, Luigi**; 79 Joo Koon Circle, Singapore 629107 (SG). **HENG, Chien Lung**; 79 Joo Koon Circle, Singapore 629107 (SG). **TOH, Yuet Shi**; 79 Joo Koon Circle, Singapore 629107 (SG). **POR, Min Yi, May**; 79 Joo Koon Circle, Singapore 629107 (SG). **LEONG, Whye Loong, Marshall**; 79 Joo Koon Circle, Singapore 629107 (SG). **TONG, Yen Wah**; 21 Lower Kent Ridge Road, Singapore 119077 (SG). **LOH, Kai Chee**; 21 Lower Kent Ridge Road, Singapore 119077 (SG). **ZHANG, Jingxin**; 21 Lower Kent Ridge Road, Singapore 119077 (SG). **LI, Wangliang**; 21 Lower Kent Ridge Road, Singapore 119077 (SG). **WOLF, Ingo Tim**; 21 Lower Kent Ridge Road, Singapore 119077 (SG).

(74) Agents: **AXIS INTELLECTUAL CAPITAL PTE LTD** et al.; 1 Pemimpin Drive, #12-07, One Pemimpin, Singapore 576151 (SG).

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(54) Title: APPARATUS AND PROCESS FOR ANAEROBIC DIGESTION

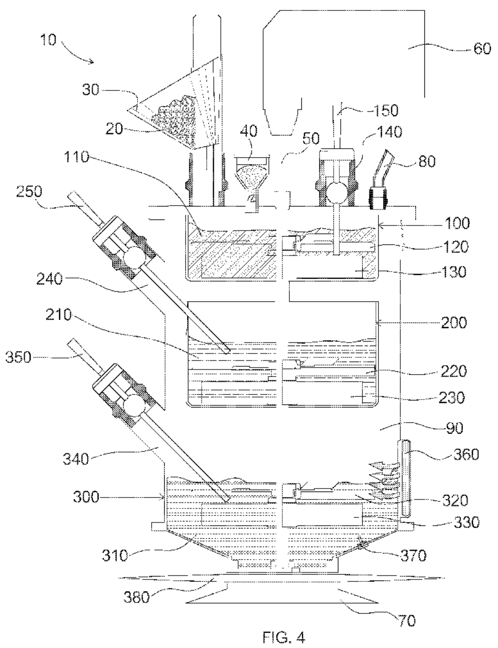

FIG. 4

(57) Abstract: An apparatus for anaerobic digestion of biodegradable matter comprising: a first chamber for producing hydrolyzed biodegradable matter from the biodegradable matter, by subjecting the biodegradable matter to hydrolysis; a second chamber for producing acidized biodegradable matter from the hydrolyzed biodegradable matter, by subjecting the hydrolyzed biodegradable matter to acidogenesis; and a third chamber for producing biogas from the acidized biodegradable matter, by subjecting the acidized biodegradable matter to methanogenesis.

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APPARATUS AND PROCESS FOR ANAEROBIC DIGESTION

Technical Field

The present disclosure generally relates to an apparatus and process for anaerobic digestion. More particularly, aspects of the present disclosure are directed to an apparatus and process for anaerobic digestion of biodegradable matter/materials, such as organic matter/materials, biowaste, biomass, household biowaste, food waste, and/or the like. The present disclosure has particular, but not exclusive, application in the management of biodegradable matter.

Background

Anaerobic digestion is a collection of processes by which microorganisms break down biodegradable materials in the absence of oxygen. During anaerobic digestion, biodegradable matter is decomposed by anaerobic bacteria and produces a gaseous by-product, i.e. biogas. Biogas mainly comprises of methane, carbon dioxide, and hydrogen sulphide. Anaerobic digestion occurs naturally but can also be used for industrial or domestic purposes, such as to manage waste and/or to produce fuels.

In various industrial settings, anaerobic digestion is mainly used for treating biodegradable matter or materials, such as organic matter, biowaste, biomass, household biowaste, food waste, and/or the like, and to produce biogas as a result. Anaerobic digestion is conducted in devices called anaerobic digesters, which treats or processes biodegradable matter in the presence of anaerobic bacteria and heat and in an oxygen-free environment. Anaerobic digestion comprises of stages in which anaerobic bacteria break down biodegradable materials from one form to another and finally yields biogas. The anaerobic bacteria that are used can be of many types depending on the type of biodegradable materials to be digested or processed.

Conventional anaerobic digestion processes are spatially and economically inefficient as the sizes of anaerobic digesters have to be increased in order to improve efficiency. Presently, the various stages of anaerobic digestion are not consolidated in an integrated anaerobic digester; each stage is processed using its own apparatus. Thus conventional anaerobic digesters occupy a lot of space and volume.

Therefore, in order to address or alleviate at least one of the aforementioned problems and/or disadvantages, there is a need to provide an apparatus and a process for anaerobic digestion, in which there are at least some improved features over the prior art.

Summary

According to a first aspect of the present disclosure, there is provided an apparatus for anaerobic digestion of biodegradable matter. The apparatus comprises: a first chamber for producing hydrolyzed biodegradable matter from the biodegradable matter, by subjecting the biodegradable matter to hydrolysis; a second chamber for producing acidized biodegradable matter from the hydrolyzed biodegradable matter, by subjecting the hydrolyzed biodegradable matter to acidogenesis; and a third chamber for producing biogas from the acidized biodegradable matter, by subjecting the acidized biodegradable matter to methanogenesis.

According to a second aspect of the present disclosure, there is provided a process for anaerobic digestion of biodegradable matter in an apparatus. The process comprises: a first step of subjecting the biodegradable matter to hydrolysis in a first chamber of the apparatus for producing hydrolyzed biodegradable matter; a second step of subjecting the hydrolyzed biodegradable matter to acidification in a second chamber of the apparatus to acidogenesis for producing acidized biodegradable matter; and a third step of subjecting the acidized biodegradable matter to methanogenesis in a third chamber of the apparatus to acidification for producing biogas.

An advantage of the present disclosure is that the apparatus and process are partitioned or segregated into distinct chambers and steps/stages. The functionalized partitioning enhances the efficiency of the hydrolysis and acidogenesis processes of the biodegradable matter, such as food waste with high solid content, thereby improving the biogas yield. There is thus a high biogas potential from the treatment or processing of the biodegradable matter, i.e. there is greater amount of useful materials, e.g. biogas, generated and reduced waste sludge or residual waste left over at the end of the anaerobic process. Another advantage is that the distinct chambers and stages are integrated in an apparatus, such that the overall space and volume taken up by the apparatus is reduced. This in turn allows the apparatus to have a smaller footprint so that it can be used in factories or industrial areas with limited space.

An apparatus and a process for anaerobic digestion according to the present disclosure is thus disclosed hereinabove. Various features, aspects, and advantages of the present disclosure will become more apparent from the following detailed description of the embodiments of the present disclosure, by way of non-limiting examples only, along with the accompanying drawings in which like numerals represent like components.

Brief Description of the Drawings

FIG. 1 is an isometric view of an apparatus according to an embodiment of the present disclosure.

FIG. 2 is a front view of an apparatus according to an embodiment of the present disclosure.

FIG. 3 is a top plan view of an apparatus according to an embodiment of the present disclosure.

FIG. 4 is a vertical cross-section view of an apparatus according to an embodiment of the present disclosure.

FIG. 5 is a flowchart of a process according to an embodiment of the present disclosure.

Detailed Description

In the present disclosure, depiction of a given element or consideration or use of a particular element number in a particular FIG. or a reference thereto in corresponding descriptive material can encompass the same, an equivalent, or an analogous element or element number identified in another FIG. or descriptive material associated therewith. The use of "/" in a FIG. or associated text is understood to mean "and/or" unless otherwise indicated. The recitation of a particular numerical value or value range herein is understood to include or be a recitation of an approximate numerical value or value range, for instance, within +/- 20%, +/- 15%, +/- 10%, +/- 5%, or +/- 0%. With respect to recitations herein directed to dimensional or numerical comparisons or equivalence, reference to the terms "generally," "approximately," or "substantially" is understood as falling within +/- 20%, +/- 15%, +/- 10%, +/- 5%, or +/- 0% of a representative / example comparison, or a specified or target value or value range; and reference to the term "essentially" is understood as falling within +/- 10%, +/- 5%, +/- 2%, +/- 1%, or +/- 0% of a representative / example comparison, or a specified or target value or value range.

As used herein, the term "set" corresponds to or is defined as a non-empty finite organization of elements that mathematically exhibits a cardinality of at least 1 (i.e., a set as defined herein can correspond to a unit, singlet, or single element set, or a multiple element set), in accordance with known mathematical definitions (for instance, in a manner corresponding to that described in *An Introduction to Mathematical Reasoning: Numbers, Sets, and Functions*, "Chapter 11: Properties of Finite Sets" (e.g., as indicated on p. 140), by Peter J. Eccles, Cambridge University Press (1998)). In general, an element of a set can include or be a system, an apparatus, a device, a structure, an object, a process, a physical parameter, or a value depending upon the type of set under consideration.

For purposes of brevity and clarity, descriptions of embodiments of the present disclosure are directed to an apparatus and a process for anaerobic digestion, in accordance with the drawings in FIG. 1 to FIG. 5. While aspects of the present disclosure will be described in conjunction with the embodiments provided herein, it will be understood that they are not intended to limit the present disclosure to these embodiments. On the contrary, the present disclosure is intended to cover alternatives, modifications, and equivalents to the embodiments described herein, which are included within the scope of the present disclosure as defined by the appended claims. Furthermore, in the following detailed description, specific details are set forth in order to provide a thorough understanding of the present disclosure. However, it will be recognized by an individual having ordinary skill in the art, i.e. a skilled person, that the present disclosure may be practiced without specific details, and/or with multiple details arising from combinations of aspects of particular embodiments. In a number of instances, well-known systems, methods, procedures, and components have not been described in detail as not to unnecessarily obscure aspects of the embodiments of the present disclosure.

In a representative or exemplary embodiment of the present disclosure, an apparatus 10 and a process 400 for anaerobic digestion are described hereinafter, with reference to FIG. 1 to FIG. 5 in general.

The apparatus 10, with reference to FIG. 1 to FIG. 4, is an anaerobic digester configured for performing anaerobic digestion of biodegradable matter or materials. The apparatus comprises three distinct sections or three chambers – a first chamber 100, a second chamber 200, and a third chamber 300. As such, the apparatus 10 may also be referred to as a three-stage anaerobic digester or an integrated anaerobic digester. Likewise, the process 400, as shown in FIG. 5, may be referred to as a three-stage anaerobic digestion process. After completion of a first stage 410 of the anaerobic digestion process 400 in the first chamber 100, the biodegradable matter in the first chamber 100 are transferred to the second chamber 200 for performing a second stage 420 of the anaerobic digestion process 400. After completion of the second stage 420 of the anaerobic digestion process 400 in the second chamber 200, the biodegradable matter in the second chamber 200 is transferred to the third chamber 300 for performing a third stage 430 of the anaerobic digestion process 400.

The first chamber 100, the second chamber 200, and the third chamber 300 are successively disposed in a vertical arrangement, with the first chamber 100 being disposed above the second chamber 200 and the third chamber 300. The first chamber 100 is thus disposed at an upper portion of the apparatus 10, the second chamber 200 is disposed below the first chamber 100, and third chamber 300 is disposed below the second chamber 200. An advantage of this vertical arrangement is that the transfer of contents or biodegradable matter from the first chamber 100 to the second chamber 200 and from the second chamber 200 to the third chamber 300 can be optimized. Additionally, the force of gravity aids or assists the transfer of contents or biodegradable matter, thereby improving the efficiency of anaerobic digestion. In the exemplary embodiment, the apparatus 10 is cylindrical in configuration. However, the apparatus 10 can also be configured or arranged in alternate ways or methods, as readily known and understood by a person having ordinary skill in the art.

The first chamber 100 is configured for performing the first stage 410 of the anaerobic digestion process 400, i.e. hydrolysis. More particularly, the first chamber 100 is configured for producing hydrolyzed biodegradable matter 110 from biodegradable matter 20, by subjecting the biodegradable matter 20 to hydrolysis.

Biodegradable matter 20 is fed or introduced into the apparatus 10, specifically the first chamber 100, through a hopper or feeder 30, which is disposed above the first chamber 100 at the upper portion of the apparatus 10. The feeder 30 may be configured to be batch-type or continuous type. In a batch-type configuration, the feeder 30 loads the first chamber 100 with biodegradable matter 20 and commences the anaerobic digestion process 400 after the loading is completed. The feeder 30 reloads the first chamber 100 with biodegradable matter 20 after the anaerobic digestion process 400 is completed. In a continuous-type configuration, biodegradable matter 20 is constantly or regularly fed into the first chamber 100 from the feeder 30. In contrast with the batch-type configuration, apparatuses 10 having the continuous-type configuration avoids interruption of the anaerobic digestion process 400 due to the loading and reloading of biodegradable matter 20.

In the exemplary embodiment, the biodegradable matter 20 comprises organic substrates of food waste or household waste that are selected and ground into small particles. It would be apparent to a person having ordinary skill in the art that the process 400 can be applied not only to the anaerobic digestion of household biowaste, but can also be applied to or in other facilities that produce organic waste matter. The biodegradable matter 20 also comprises inoculants which are added into the food waste for implanting microorganisms or anaerobic bacteria therein. The treated biodegradable matter 20 is then fed into the first chamber 100 of the apparatus 10 via the feeder 30. Alternatively, fresh organic waste matter can be fed directly into the first chamber 100 via the feeder 30.

The apparatus 10 further comprises a dosing vent 40 disposed above the first chamber 100. Alkali substances such as alkali solution or powder can be added into the first chamber 100 containing the biodegradable matter 20, in order to adjust or maintain the pH of the biodegradable matter 20. The dosing vent 40 may thus be referred to as an alkali dosing vent. The maintenance of the pH of the biodegradable matter 20 in the first chamber 100 provides an advantage of optimizing the rate of microbial action or optimizing microbial activity. The optimization of microbial activity in turn improves the efficiency of the anaerobic digestion process 400, as microbial activity is a part of the anaerobic digestion process 400.

The biodegradable matter 20 in the first chamber 100 is subjected to a chemical process of hydrolysis in the first stage 410 of the anaerobic digestion process 400. During the hydrolysis process, hydrolyzed biodegradable matter 110 is produced from biodegradable matter 20. More particularly, macromolecular organic matter in the biodegradable matter 20 is converted into smaller molecular substances and organic acids of the hydrolyzed biodegradable matter 110. The residence time of the biodegradable matter 20 and the resultant hydrolyzed biodegradable matter 110 in the first chamber 100 is at least 1 day, depending on the contents in the first chamber 100. An example of an optimal time for completion of the hydrolysis process in the first chamber 100 is approximately 2 days.

During feeding or loading of the biodegradable matter 20 into the apparatus 10, the first chamber 100 is open to the feeder 30 and the dosing vent 40. The fluid communications between the first chamber 100 and each of the feeder 30 and the dosing vent 40 are pinched off once the contents or biodegradable matter 20 in the feeder 30 and the alkali substances in the dosing vent 40 are emptied into the first chamber 100. The first chamber 100 is connected through a suitable opening, conduit or piping mechanism to the second chamber 200, wherein the opening is configured for emptying the processed contents from the first chamber 100 to the second chamber 200. Specifically, after the hydrolysis process in the first stage 410 of the anaerobic digestion process 400, the hydrolyzed biodegradable matter 110 in the first chamber 100 is transferred into the second chamber 200 via the opening of the first chamber 100. The opening may be activated, i.e. opened or closed, using mechanisms known to a person having ordinary skill in the art. An example of such a mechanism is a toggle latch located on the outside of the first chamber 100. The toggle latch, when activated, allows for the transfer of the contents from the first chamber 100 to the second chamber 200.

The second chamber 200 is configured for performing the second stage 420 of the anaerobic digestion process 400, i.e. acidogenesis. More particularly, the second chamber 200 is configured for producing acidized biodegradable matter 210 from hydrolyzed biodegradable matter 110, by subjecting the hydrolyzed biodegradable matter 110 to acidogenesis.

The hydrolyzed biodegradable matter 110 in the second chamber 200 is subjected to a chemical process of acidogenesis in the second stage 420 of the anaerobic digestion process 400. During the acidogenesis process, acidized biodegradable matter 210 are produced from hydrolyzed biodegradable matter 110. More particularly, various organic acids in the hydrolyzed biodegradable matter 110 are converted into acetates and partial methane. As methane is also partially produced during the conversion of the hydrolyzed biodegradable matter 110 into acidized biodegradable matter 210, the process of acidogenesis may also be referred to as a preliminary methanogenesis process. The residence time of the hydrolyzed biodegradable matter 110 and the resultant acidized biodegradable matter 210 in the second chamber 200 is at least 1 day, depending on the contents in the second chamber 200. An example of an optimal time for completion of the acidogenesis process in the second chamber 200 is approximately 2 days.

Because the pH of the contents is already controlled in the first chamber 100, the hydrolzed biodegradable matter 110 will have a pH within a desired range. The pH of the contents in the second chamber 200 can be controlled by controlling the pH of the hydrolzed biodegradable matter 110 while it is still in the first chamber 100, i.e. by using the dosing vent 40. The hydrolzed biodegradable matter 110, with the desired pH, is then transferred from the first chamber 100 to the second chamber 200.

The second chamber 200 is connected through a suitable opening, conduit or piping mechanism to the third chamber 300, wherein the opening is configured for emptying the processed contents from the second chamber 200 to the third chamber 300. Specifically, after the acidogenesis process in the second stage 420 of the anaerobic digestion process 400, the acidized biodegradable matter 210 in the second chamber 200 is transferred into the third chamber 300 via the opening of the second chamber 200. The opening may be activated, i.e. opened or closed, using mechanisms known to a person having ordinary skill in the art. An example of such a mechanism is a toggle latch located on the outside of the second chamber 200. The toggle latch, when activated, allows for the transfer of the contents from the second chamber 200 to the third chamber 300.

The third chamber 300 is configured for performing the third stage 430 of the anaerobic digestion process 400, i.e. methanogenesis. More particularly, the third chamber 300 is configured for producing biogas 310 from acidized biodegradable matter 210, by subjecting the acidized biodegradable matter 210 to methanogenesis.

The acidized biodegradable matter 210 in the third chamber 300 is subjected to a chemical process of methanogenesis in the third stage 430 of the anaerobic digestion process 400. During the methanogenesis process, biogas 310, which comprises substantially of methane and carbon dioxide, is produced from acidized biodegradable matter 210. More particularly, organic acids in the acidized biodegradable matter 210 are primarily converted into methane. As such, the process of methanogenesis may also be referred to as a deep methanogenesis process. Deep methanogenesis involves better and improved conversion of organic acids to methane, when compared to the acidogenesis process or preliminary methanogenesis in the second stage 420 of the anaerobic digestion process 400. The residence time of the acidized biodegradable matter 210 and the resultant biogas 310 in the third chamber 300 is at least 1 day, depending on the contents in the third chamber 300. An example of an optimal time for completion of the methanogenesis process in the third chamber 300 is approximately 2 days. Completion of the methanogenesis process, or deep methanogenesis, in the third stage 430 of the anaerobic digestion process 400 indicates completion of the three-stage anaerobic digestion process 400.

The pH of the contents in the third chamber 300 would have been stabilized due to the pH controls in the preceding chambers (100 and 200). In some embodiments, the apparatus 10 comprises a second dosing vent that opens into the third chamber 300. The second dosing vent is configured for adding alkali substances to directly control the pH of the contents in the third chamber 300.

In the exemplary embodiment, the apparatus 10 further comprises a stirrer 50 positioned to extend along a central vertical axis of the apparatus 10. The stirrer 50, particularly a central shaft thereof, is coupled or connected to a motor 60 for imparting rotary motion to the stirrer 50. The motor 60 is configured for adjusting the rotational speed of the stirrer 50, depending on the contents in the respective chambers of the apparatus 10. The stirrer 50 extends through and into each of the first chamber 100, second chamber 200, and third chamber 300, such that when the motor 60 is operating, the stirrer 50 continuously or continually stirs the contents in the respective chambers of the apparatus 10. The stirring of the contents enable improved mixing and produces optimal conditions for generating biogas 310, which is the main end-product of the anaerobic digestion process 400. Thus, the use of the stirrer 50 in the apparatus 10 advantageously increases the overall efficiency of the anaerobic digestion process 400.

To facilitate the stirring and mixing, the stirrer 50 comprises blades extending from the central shaft of the stirrer 50 laterally into the respective chambers of the apparatus 10. Specifically, with reference to FIG. 4, the first chamber 100 comprises upper blades 120 and lower blades 130 laterally extended from the stirrer 50. Similarly, the second chamber 200 comprises upper blades 220 and lower blades 230 laterally extended from the stirrer 50, and the third chamber 300 comprises upper blades 320 and lower blades 330 laterally extended from the stirrer 50. The blades (120, 130, 220, 230, 320, and 330) in each of the first chamber 100, second chamber 200, and third chamber 300, are arranged to stir and mix the contents in the respective chambers, as a result of the operation of the stirrer 50 and the motor 60. The number of blades in each of the chambers of the apparatus 10 can be varied or adjusted, as readily understood by a person having ordinary skill in the art.

As shown in FIG. 4, each of the chambers of the apparatus 10 comprises a sampling port for taking a sample from or sampling the contents in the chambers. Specifically, the first chamber 100 comprises a first sampling port 140 for sampling the contents in the first chamber 100 using a first sampling device 150. Similarly, the second chamber 200 comprises a second sampling port 240 for sampling the contents in the second chamber 200 using a second sampling device 250, and the third chamber 300 comprises a third sampling port 340 for sampling the contents in the third chamber 300 using a third sampling device 350.

The first sampling port 140 is attached to a top portion of the first chamber 100. The second sampling port 240 is attached to a side portion of the second chamber 200. The third sampling port 340 is attached to a side portion of the third chamber 300. Each of the sampling ports (140, 240, and 340) comprises a vent or an opening into the respective chambers, wherein the vent or opening is configured to receive the respective sampling devices (150, 250, and 350). Each of the sampling ports (140, 240, and 340) is arranged to dispense, into the respective sampling devices (150, 250, and 350), a sample or samples of the contents present in or being processed in the respective chambers of the apparatus 10. Alternatively, the sampling devices may be configured to extract sample or samples from the respective chambers. The dispensing (or extraction) of the sample(s) serves to test the contents in the respective chambers in terms of the chemical composition, consistency, and other parameters of the various stages (410, 420, and 430) of the anaerobic digestion process 400.

The apparatus 10 further comprises a heat jacket or temperature jacket 360 disposed or fitted around the third chamber 300. The temperature jacket 360 is configured for applying or transferring heat to the contents in the third chamber 300 during the third stage 430 of the anaerobic digestion process 400. The temperature jacket 360 can comprise any suitable industrial heater for generating heat. The temperature jacket 360 is disposed or positioned at a side of the third chamber 300. The third chamber 300 further comprises an arrangement to hold a temperature probe or temperature sensor 370 for measuring the temperature of the contents in the third chamber 300. The temperature sensor 370 is disposed or positioned at a bottom portion of the third chamber 300. The measurement of the temperature of the contents in the third chamber 300 enables better control of the heat generated by the temperature jacket 360 and transferred to the third chamber 300. The control of the heat generated and temperature of the contents in the third chamber 300 advantageously optimizes the methanogenesis process, i.e. third stage 430 of the anaerobic digestion process 400, occurring in the third chamber 300.

The third chamber 300 of the apparatus 10 also comprises a discharge port 380 at the bottom portion of the third chamber 300. The discharge port 380 is configured for the removal of the contents in the third chamber 300 after the methanogenesis process. During the third stage 430 of the anaerobic digestion process 400, biogas 310 is generated by the methanogenesis process. However, residual waste is also left behind in the third chamber 300 as a result of the methanogenesis process. The residual waste is discharged out of the third chamber 300 through the discharge port 380, after each of the first stage 410, second stage 420, and third stage 430 is completed. The discharge port 380 may be activated, i.e. opened or closed, using mechanisms known to a person having ordinary skill in the art. An example of such a mechanism is a toggle latch located on the outside of the third chamber 300. The toggle latch, when activated, allows for the residual waste in the third chamber 300 to be discharged out of the apparatus 10. The time taken to complete the entire three-stage anaerobic digestion process 400, before the residual waste is removed, is at least 3 days.

Additionally, the apparatus 10 comprises a stand or support 70 at the bottom of the apparatus 10. The support 70 is configured for supporting the apparatus 10, specifically the first chamber 100, second chamber 200, and third chamber 300. Further, the support 70 provides support to the third chamber 300 such that the third chamber 300 is raised off and above the ground level. The raised profile of the third chamber 300 advantageously allows for removal of the residual waste through the discharge port 380.

The apparatus 10 further comprises a biogas vent 80 disposed at the top of the apparatus 10. Specifically, the biogas vent 80 is disposed proximate to the feeder 30 and the dosing vent 40. The third chamber 300 in the apparatus 10 is open to an internal cavity 90 of the apparatus 10, wherein the internal cavity 90 allows for fluid communication between the third chamber 300 and the biogas vent 80. As the biogas 310 generated by the third chamber 300 from the methanogenesis process is a gaseous substance, the biogas 310 rises up inside the apparatus 10 and specifically inside the internal cavity 90. The biogas 310 rises up towards the biogas vent 80 and is extracted through the biogas vent 80. During the acidogenesis process in the second stage 420 of the anaerobic digestion process 400, there may be some biogas or methane generated or produced in the second chamber 200. The biogas or methane in the second chamber 200 may also escape into the internal cavity 90 and be extracted from the biogas vent 80. The biogas 310 that is extracted from the biogas vent 80 is stored in a biogas bag for subsequent usage or processing, which would occur outside of the apparatus 10.

An advantage of the apparatus 10 and three-stage anaerobic digestion process 400 is an improvement in the efficiency of methane conversion as the chemical processes are segregated, because each of the first chamber 100, second chamber 200, and third chamber 300 are partitioned from one another within the apparatus 10. The segregation of the processes, i.e. segregation of the first stage 410, second stage 420, and third stage 430, in turn leads to a reduction in the wastage of base materials that are converted into methane or biogas 310. The biodegradable matter 20 that is fed into the apparatus 10 is subjected to a preliminary methanogenesis process (in the second chamber 200 during the second stage 420) and a deep methanogenesis process (in the third chamber 300 during the third stage 430). This subsequently results in an improvement in the efficiency of methane conversion. Segregation of the anaerobic digestion process 400 into different steps or stages (410, 420, and 430) facilitates addition or augmentation, i.e. bio-augmentation, of required microorganisms, e.g. bacteria, individually in each of the stages (410, 420, and 430). More bacterial species capable of acetogenesis, amino-acid-utilization and symbiosis, and multi-function methanogens are enriched in the apparatus 10.

The partition of the chambers (100, 200, and 300) in the apparatus 10 and the segregation of the stages (410, 420, and 430) in the anaerobic digestion process 400 enable greater control of each chamber and stage, while the integration of all the three chambers and stages maintains a closed and isolated system for the apparatus 10 and the entire anaerobic digestion process 400. For example, optimal conditions can be applied in each of the chambers or stages, such as optimum pH control, thereby improving the overall efficiency of the apparatus 10 and the anaerobic digestion process 400.

The three-stage anaerobic digestion process 400 also facilitates anaerobic digestion of biodegradable matter 20 or organic waste that contains a higher percentage of solids, i.e. high-solids. The three-stage anaerobic digestion process 400 is more efficient in digesting the high-solids as compared to conventional anaerobic digestion processes. This also allows digestion of biodegradable matter 20 or organic waste that contains a higher percentage of organic matter in the total waste matter fed into the apparatus 10. The biogas 310 generated or produced by the apparatus 10 in the anaerobic digestion process 400 is 20% to 40% more than conventional anaerobic digestion processes. The bio-augmentation and functionalized partitions of the chambers in the apparatus 10 allows the apparatus 10 to achieve high digestion efficiency for high-solid organic waste. Additionally, the apparatus 10 is capable of high organic loading, and shows high buffering capacity even when exposed to high organic loading.

High anaerobic digestion efficiency or an improvement in efficiency may in turn allow for smaller chambers or components of the apparatus 10 to be used, thereby reducing the space and volume, i.e. footprint, occupied by the apparatus 10. The improvement in efficiency may also reduce the energy consumption of the apparatus 10, thereby reducing costs. Moreover, the vertical arrangement of the chambers (100, 200, and 300) of the apparatus 10 provides a stacked relationship for the chambers, thereby reducing the footprint of the apparatus 10. This advantageously allows the apparatus 10 to be of a smaller or reduced size, such that it can be used in factories or industrial areas with limited space.

In an example of using the apparatus 10 in a three-stage anaerobic digestion process 400, the apparatus 10 is segregated into three distinct chambers – first chamber 100, second chamber 200, and third chamber 300. The first chamber 100 is configured for performing the hydrolysis process of the first stage 410, the second chamber 200 is configured for performing the acidogenesis process of the second stage 420, and the third chamber 300 is configured for performing the methanogenesis process of the third stage 430. Biodegradable matter 20 containing high percentage of solids, i.e. high-solids, is fed into the first chamber 100.

During the hydrolysis process, or high-solids hydrolysis process, in the first stage 410, the apparatus 10, specifically the first chamber 100 containing the biodegradable matter 20, is operated at a temperature of 35°C, the stirrer 50 and motor 60 are adjusted to rotate the stirrer 50 at a rotational speed of 150 rpm, and the pH is optimally maintained at approximately 5.5 ±0.2. The pH is maintained by adding sodium bicarbonate into the first chamber 100 via the dosing vent 40. Additionally or alternatively, other alkali substances may be added instead of sodium bicarbonate. After around 1-2 days of operation to produce hydrolyzed biodegradable matter 110 from the biodegradable matter 20 fed into the first chamber 100, the hydrolyzed biodegradable matter 110 is stored at a temperature of –20°C in order to freeze it.

The hydrolyzed biodegradable matter 110 is subsequently transferred from the first chamber 100 to the second chamber 200 for the second stage 420. During the acidogenesis process in the second stage 420, or the acidification stage, the pH is controlled or maintained at approximately 6.5 ±0.2 in order to provide the optimal conditions for the acidogenesis process. After around 1-2 days of operation to produce acidized biodegradable matter 210 from the hydrolyzed biodegradable matter 110, the acidized biodegradable matter 210 is transferred from the second chamber 200 to the third chamber 300 for the third stage 430. The third stage 430 may also be referred to as a wet methane-producing stage for methane production, or methanogenesis. During the methanogenesis process in the third stage 430, the acidized biodegradable matter 210 is converted into biogas 310, which is the final product of the three-stage anaerobic digestion process 400.

In the foregoing detailed description, embodiments of the present disclosure in relation to an apparatus and a process for anaerobic digestion are described with reference to the provided figures. The description of the various embodiments herein is not intended to call out or be limited only to specific or particular representations of the present disclosure, but merely to illustrate non-limiting examples of the present disclosure. The present disclosure serves to address at least some of the mentioned problems and issues associated with the prior art. Although only some embodiments of the present disclosure are disclosed herein, it will be apparent to a person having ordinary skill in the art in view of this disclosure that a variety of changes and/or modifications can be made to the disclosed embodiments without departing from the scope of the present disclosure. The scope of the disclosure as well as the scope of the following claims is not limited to embodiments described herein.

Claims

1. An apparatus for anaerobic digestion of biodegradable matter, the apparatus comprising:

a first chamber for producing hydrolyzed biodegradable matter from the biodegradable matter, by subjecting the biodegradable matter to hydrolysis;

a second chamber for producing acidized biodegradable matter from the hydrolyzed biodegradable matter, by subjecting the hydrolyzed biodegradable matter to acidogenesis; and

a third chamber for producing biogas from the acidized biodegradable matter, by subjecting the acidized biodegradable matter to methanogenesis.

2. The apparatus as in claim 1, wherein the first chamber, second chamber, and third chamber are successively disposed in a vertical arrangement.

3. The apparatus as in claim 1 or 2, wherein the first chamber is disposed above the second chamber and third chamber.

4. The apparatus as in claim 1 or 2, wherein the first chamber, second chamber, and third chamber are partitioned from one another within the apparatus.

5. The apparatus as in claim 1, further comprising a biogas vent for extracting the biogas away from the apparatus.

6. The apparatus as in claim 1, further comprising a dosing vent for controlling pH of contents in the first chamber.

7. The apparatus as in claim 6, wherein the pH is controlled by adding an alkali substance through the dosing vent.

8. The apparatus as in claim 1, further comprising a stirrer for stirring contents in at least one of the first chamber, second chamber, and third chamber.

9. The apparatus as in claim 9, the stirrer comprising a plurality of blades laterally extending into at least one of the first chamber, second chamber, and third chamber.

10. The apparatus as in claim 8 or 9, further comprising a motor coupled to the stirrer for operating the stirrer.

11. The apparatus as in claim 1, wherein at least one of the first chamber, second chamber, and third chamber comprises a sampling port.

12. The apparatus as in claim 11, wherein the sampling port is configured for dispensing a sample from the at least one of the first chamber, second chamber, and third chamber.

13. The apparatus as in claim 12, wherein the sampling port is configured for receiving a sampling device for extracting the sample.

14. A process for anaerobic digestion of biodegradable matter in an apparatus, the process comprising:

a first step of subjecting the biodegradable matter to hydrolysis in a first chamber of the apparatus for producing hydrolyzed biodegradable matter;

a second step of subjecting the hydrolyzed biodegradable matter to acidification in a second chamber of the apparatus to acidogenesis for producing acidized biodegradable matter; and

a third step of subjecting the acidized biodegradable matter to methanogenesis in a third chamber of the apparatus to acidification for producing biogas.

15. The process as in claim 14, further comprising controlling pH of at least one of the first chamber, second chamber, and third chamber.

16. The process as in claim 14, further comprising stirring contents in at least one of the first chamber, second chamber, and third chamber.

17. The process as in claim 14, further comprising extracting the biogas away from the apparatus.

18. The process as in claim 14, further comprising dispensing a sample from at least one of the first chamber, second chamber, and third chamber.

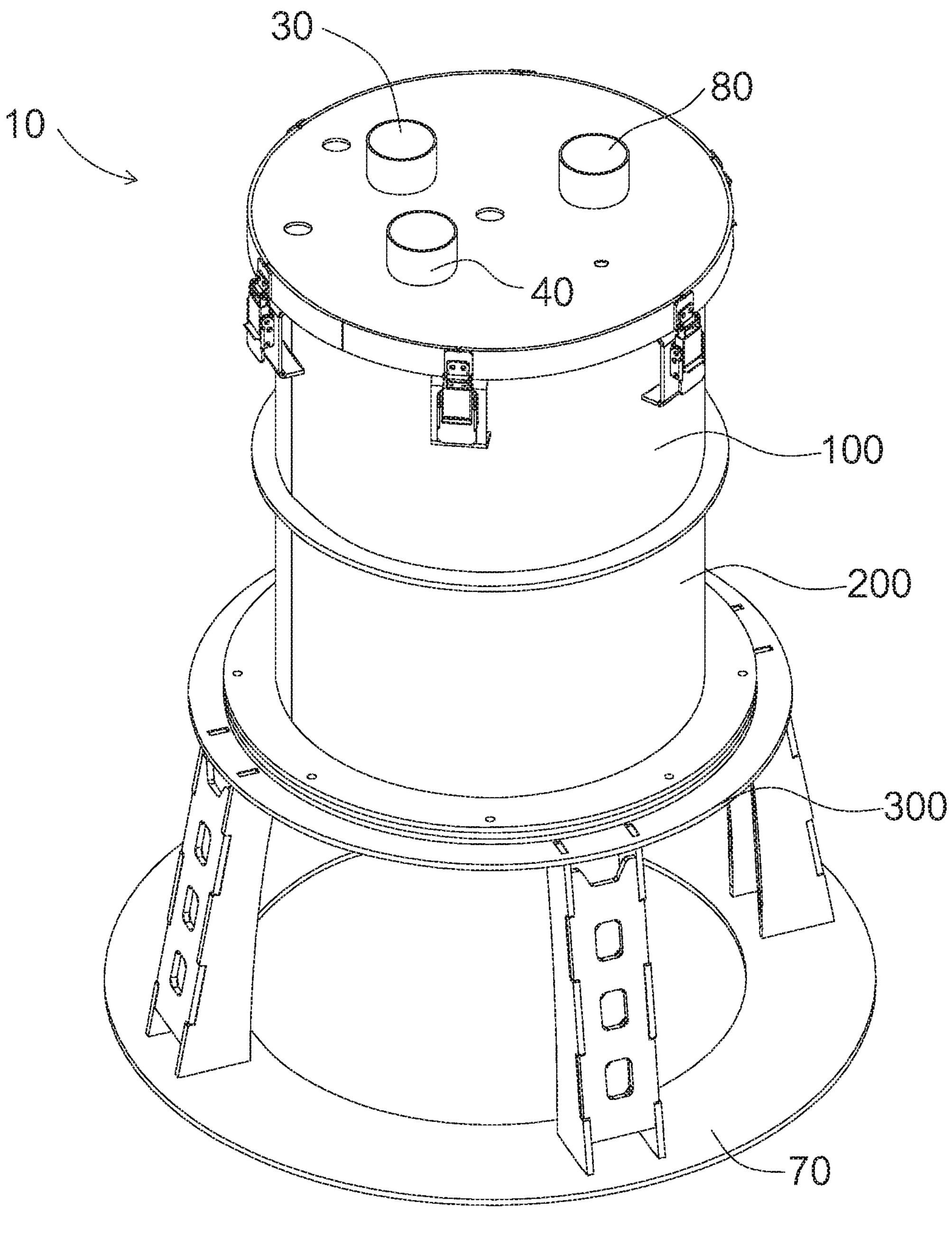

FIG. 1

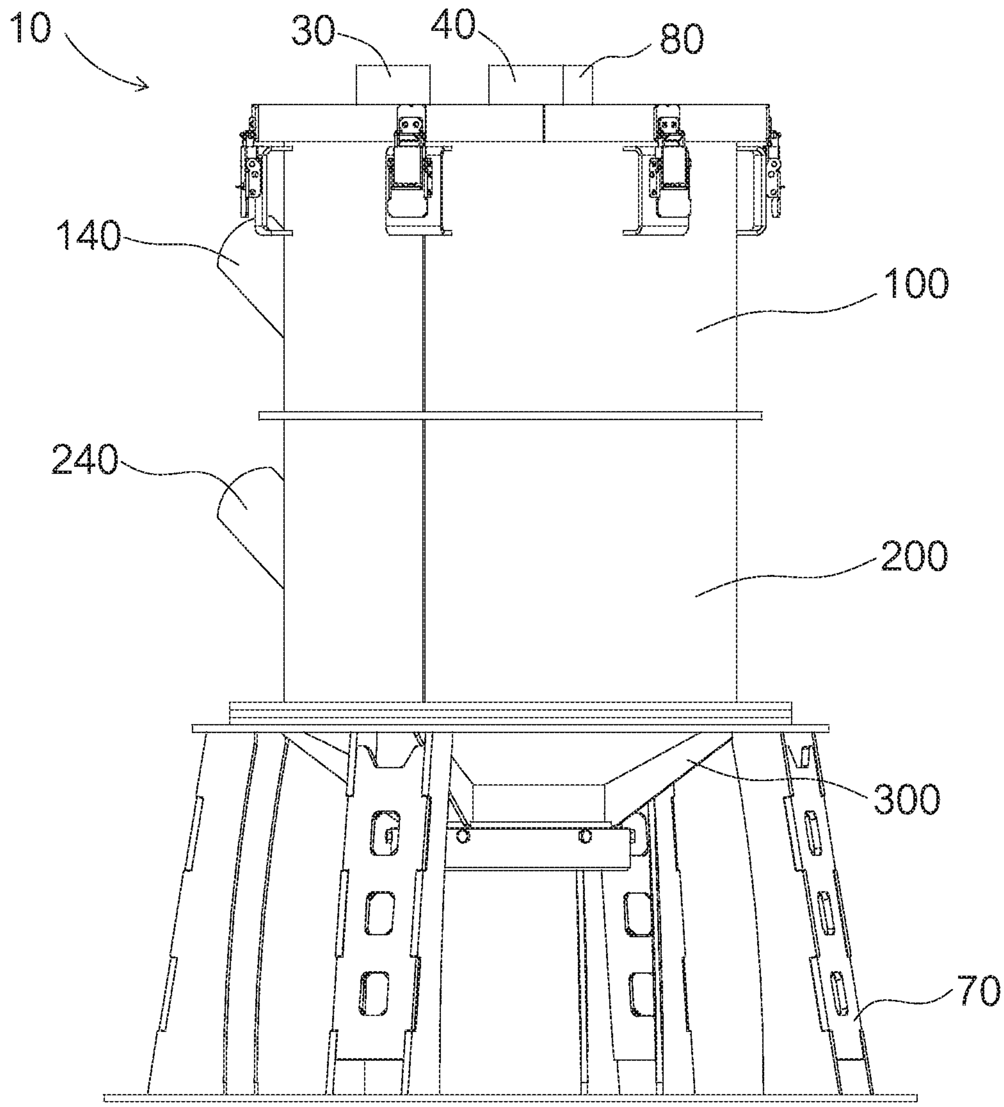

FIG. 2

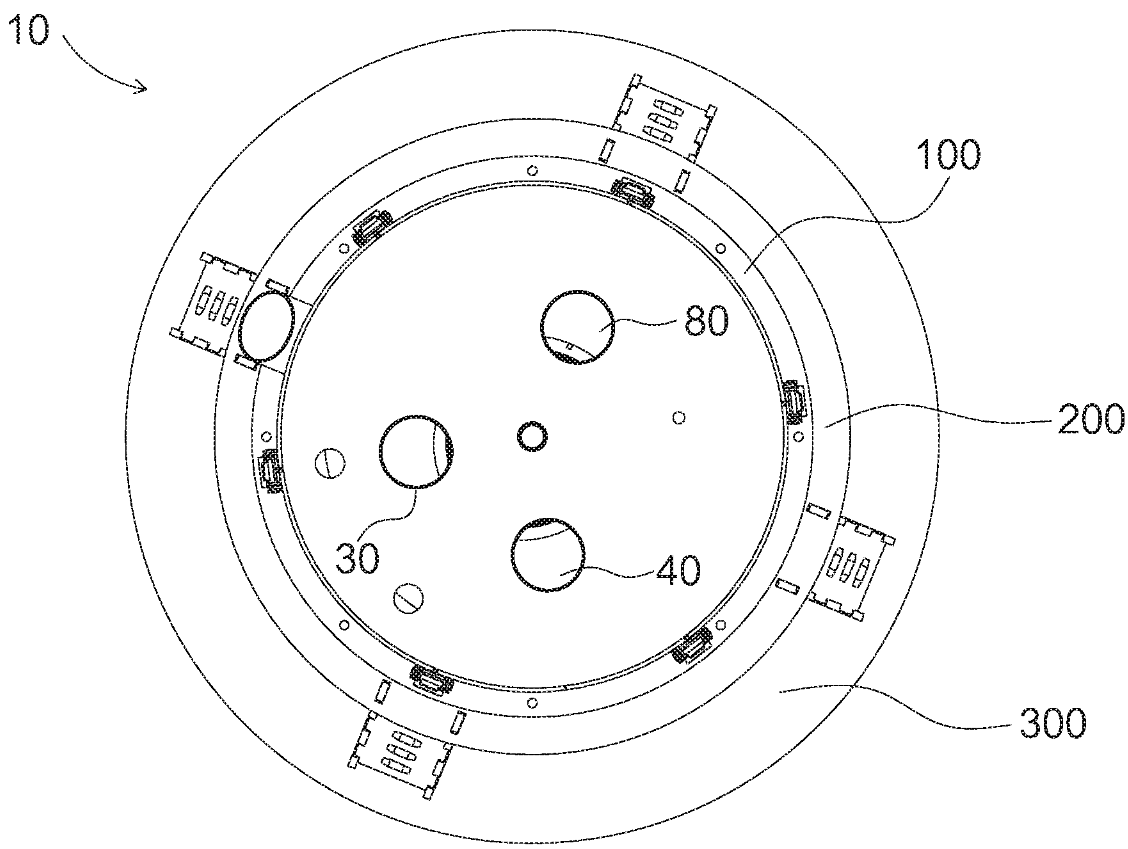

FIG. 3

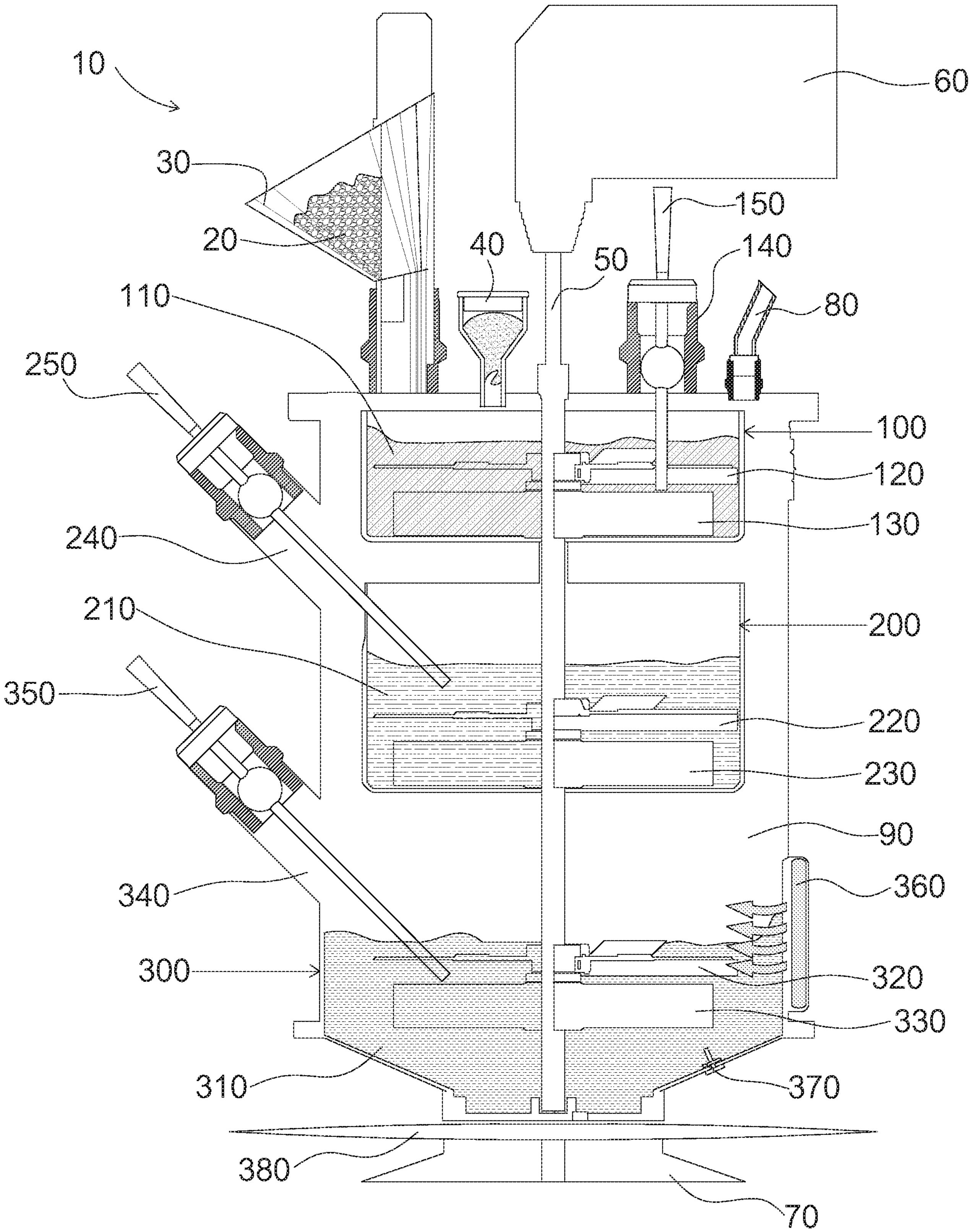
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FIG. 4

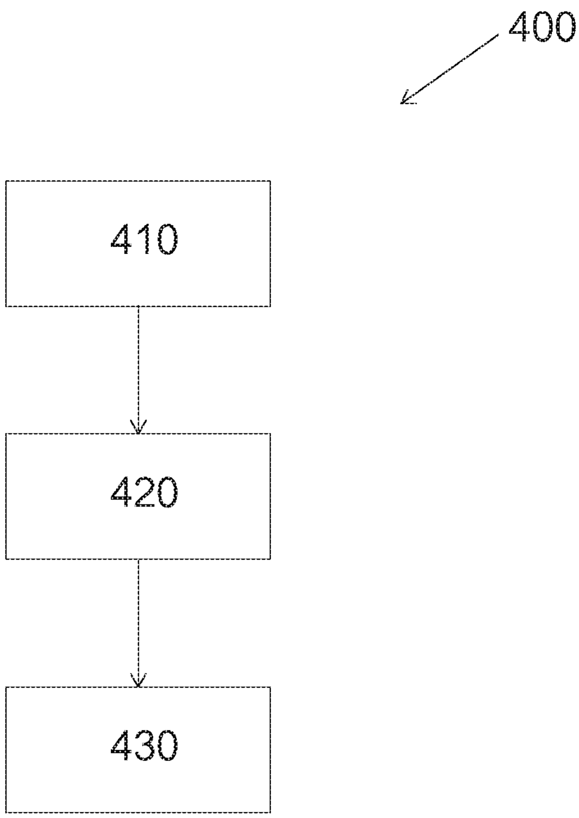

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2015/050137

A. CLASSIFICATION OF SUBJECT MATTER

B09B 3/00(2006.01)i, C02F 11/04(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B09B 3/00; C12M 1/00; C02F 1/52; C02F 3/28; C12N 9/14; C02F 3/00; C02F 3/34; C02F 11/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: anaerobic, digestion, hydrolyze, acidogenesis, methanogenesis, vertical

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011-0136213 A1 (STEWART, W. C.) 9 June 2011 See abstract; paragraphs [0044]-[0062]; figures 1-3; and claims 1-15.	1,5-18
Y		2-4
Y	US 2004-0134853 A1 (MILLER III, H. P.) 15 July 2004 See abstract; figure 4; and claims 1-15.	2-4
A	US 2005-0130290 A1 (CHOATE, C. E. et al.) 16 June 2005 See abstract; figures 1-4; and claims 19-29.	1-18
A	US 2010-0105127 A1 (GINSBURG, M. A.) 29 April 2010 See abstract; figures 1-2E; and claims 1-23.	1-18
A	US 5591342 A (DELPORTE, C. et al.) 7 January 1997 See abstract; figure 1; and claims 1-4.	1-18

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 August 2015 (11.08.2015)	**17 August 2015 (17.08.2015)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 35208, Republic of Korea
Facsimile No. +82-42-472-7140

Authorized officer
LEE, Dong Wook
Telephone No. +82-42-481-8163

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