

## **Method and apparatus for carbon dioxide capture and energy recovery enhancement**

### **Field of Invention**

This invention relates to an improved method and apparatus for use in the capture of carbon dioxide and energy recovery from anaerobic digestion.

### **Background of the Invention**

The listing or discussion of a prior-published document in this specification should not necessarily be taken as an acknowledgement that the document is part of the state of the art or is common general knowledge.

Current state-of-the-art anaerobic systems include anaerobic digesters, two-phase systems, upflow anaerobic sludge blankets (UASBs), expanded granular sludge beds (EGSBs), anaerobic filters, anaerobic baffled tanks, anaerobic sequencing batch reactors (anSBRs), and, of late, anaerobic membrane bioreactors (MBRs). In such systems, the organic feed stream is anaerobically degraded by way of hydrolysis (if particulates are present), acidogenesis (a subset of which is acetogenesis) and methanogenesis. Acidogenesis results in volatile fatty acids (VFAs), carbon dioxide (CO<sub>2</sub>), and small quantities of hydrogen (H<sub>2</sub>). Methanogenesis results in carbon dioxide and methane (CH<sub>4</sub>).

The biogas resulting from an anaerobic system typically comprises CH<sub>4</sub> and CO<sub>2</sub>, with substantially smaller quantities of gases like hydrogen sulphide (H<sub>2</sub>S) and nitrogen (N<sub>2</sub>). The percentage of CH<sub>4</sub> and CO<sub>2</sub> in the biogas resulting from a full anaerobic system can be 40-65% for CH<sub>4</sub>, with the balance largely being CO<sub>2</sub>. Where biogas is used to reclaim energy (e.g. from raw sewage), the CO<sub>2</sub> represents "lost" carbon which cannot contribute to the energy reclaimed from CH<sub>4</sub> when biogas is combusted. This CO<sub>2</sub>, and the CO<sub>2</sub> arising from the combustion of CH<sub>4</sub>, is typically vented into the atmosphere.

With the exception of the two-phase system, the anaerobic systems identified above do not separate the acidogenesis phase from the methanogenesis phase. This means that the majority of the above mentioned systems generate a single stream of biogas that combines the CO<sub>2</sub> from acidogenesis with the CO<sub>2</sub> and CH<sub>4</sub> from methanogenesis. In such systems,

the pH of the system must be carefully controlled because methanogenesis is sensitive to both low and high pH values, meaning that the pH needs to be maintained in a range of from 6.5 to 8.

To enhance anaerobic digestion, a two-phase anaerobic process and system can be used instead. This approach allows for optimization of operating conditions for acidogenesis and methanogenesis separately, and thus optimizes the conditions to sustain specific microbes involved in the different stages of the conversion of material to biogas. These two stages take place simultaneously in two different reactors and provide the optimal conditions for acidogens and methanogens, thus enhancing the performance of the overall system, which includes methane production and carbon dioxide fixation. However, it has been noted in the laboratory and at full-scale installations that complete phase separation (i.e. full separation of the acidogenic and methanogenic phases) has not been achieved. This means that the gas from the acidogenic phase will contain a little CH<sub>4</sub> (< 20%).

In the acidogenic phase, the primary objective is conversion of biodegradable organics to volatile fatty acids (VFAs). The acidogens responsible for VFA conversion are predominantly present in acidogenic sludge, which includes:

- (1) fermentative bacteria which are responsible for the production of VFA;
- (2) hydrogen producing acetogenic bacteria, which metabolizes propionic acid, other VFAs and alcohols into acetate and H<sub>2</sub>; and
- (3) homoacetogens which use H<sub>2</sub> and CO<sub>2</sub> to produce acetate.

In the methanogenic phase, VFAs produced in acidogenic phase are consumed to produce methane.

While there are existing methods for concentrating the CH<sub>4</sub> in the biogas by removing the CO<sub>2</sub>, these methods are largely physico-chemical in nature and involve scrubbing and sorption, pressure swing, and membrane separation. However, all of these methods do not convert the CO<sub>2</sub> which has been separated from the CH<sub>4</sub> into a useful product. The resulting CO<sub>2</sub> stream is typically vented into the atmosphere. Alternatively, the CO<sub>2</sub> collected as discussed above or CO<sub>2</sub> from an external supply can also be supplied to anaerobic systems to improve acid production by bacterial microorganisms. However, the produced acids need to be further degraded to generate CH<sub>4</sub> in a subsequent system instead of being readily converted to CH<sub>4</sub>.

There remains a need for improved systems and methods that can enhance the capture of carbon from anaerobic digestion.

### Summary of Invention

In a first aspect of the invention, there is provided an acidogenic reactor system for use in a wastewater treatment plant, said system comprising an inhibitor, wherein the inhibitor is one or more volatile fatty acids and/or  $H_2$  that is capable of regulating a microbial population. Further embodiments of this aspect are described in Claims 2 to 15 below.

In embodiments of the invention, the concentration of  $H_2$  in the reactor is from 20 to 40% and/or the concentration of the one or more volatile fatty acids is greater than or equal to 3000 mg/L. Preferably, in a start-up phase of the reactor, the concentration of  $H_2$  in the reactor is from 20 to 40% and in full operation the concentration of the one or more volatile fatty acids is greater than or equal to 3000 mg/L while the concentration of  $H_2$  is less than 20% (e.g. from 0% to less than 20%).

In yet further embodiments of the invention, the acidogenic reactor system in operation further comprises an anaerobic sludge that comprises a microbial community of about 90% Eubacteria and about 10% *Archaea*. For example, the microbial community comprises fermentative bacteria; hydrogen producing acetogenic bacteria; homoacetogens; and one or more  $H_2$ -consuming methanogens of the *Archaea* group. In embodiments of the invention, said one or more  $H_2$ -consuming methanogens of the *Archaea* group are capable of functioning in an acidic environment. For example, the one or more  $H_2$ -consuming methanogens of the *Archaea* group comprise *Methanobacteriales* (MBT) and/or *Methanomicrobiales* (MMB).

In embodiments of the invention, the concentration of  $H_2$  and/or the concentration of the one or more volatile fatty acids is wholly generated *in situ* by a microbial population within the acidogenic sludge or, more preferably, is partly generated *in situ* by the microbial population and partly supplied by a supplementary stream of  $H_2$  and/or one or more volatile fatty acids. When used herein, a supplementary source is an external source supplied to the reactor for use therein. In yet further embodiments, the entire concentrations of the inhibitors used may be supplied from external sources.

In embodiments of the invention, the reactor system is substantially free of biofilms (e.g. does not contain biofilms).

In embodiments of the invention, the wastewater treatment plant is a sewage plant or an industrial wastewater plant.

In yet further embodiments of the invention, the acidogenic reactor system is fitted upstream of a one-stage anaerobic reactor or a methanogenic reactor. For example, the acidogenic reactor system is fitted upstream of a methanogenic reactor.

In yet still further embodiments of the invention, the acidogenic reactor system further comprises an apparatus for recycling biogas produced by the acidogenic reactor system back into said acidogenic reactor system.

In further embodiments of the invention, the acidogenic reactor system further comprises pH, oxidation reduction potential (ORP) and temperature controllers.

In a second aspect of the invention, there is provided a method of generating biogas using an acidogenic reactor system, said method comprising the steps of:

- (i) seeding the acidogenic reactor with anaerobic sludge as seed from an existing anaerobic system;
- (ii) adding anaerobic sludge to the acidogenic reactor in a sequential batchwise or a continuous manner (e.g. a sequential batchwise manner);
- (iii) maintaining a pH range within the acidogenic reactor of 5.0-5.5 and a temperature between 30 and 50°C (e.g. between 37 and 42°C);
- (iv) manipulating the concentration of an inhibitor in the acidogenic reactor to regulate the microbial population, where the inhibitor is selected from one or more volatile fatty acids and/or H<sub>2</sub>;
- (v) optionally recycling the biogas produced within the acidogenic reactor to the acidogenic reactor for further reaction (e.g. recycling the biogas until the H<sub>2</sub> content of the biogas produced in the batch is approximately 0% and then storing the resulting biogas);
- (vi) transferring the treated anaerobic sludge to a downstream reactor of the one-stage anaerobic type or of the methanogenic type; and
- (vii) repeating steps (iii) to (vi).

Further embodiments of this aspect are contained within Claims 17 to 21 below.

In a third aspect of the invention, there is provided a use of volatile fatty acids (VFAs) and/or  $H_2$  to regulate the microbial population of an acidogenic reaction. Further embodiments of this aspect are described in Claims 23 and 24 below.

### Description

The invention will now be described in further detail below, with the aid of the following figures.

Fig. 1 reaction scheme for conversion of  $CO_2$  to  $CH_4$

Fig. 2 biogas contents variation of acidogenic phase

Fig. 3 FISH profile of Archaea (red) of acidogenic sludge

Fig. 4 ratio of hydrogen-trophic and acetic-trophic methanogen quantified by qPCR in acidogenic reactor over a 120 day period

When used herein, "downstream" means that a particular reactor etc is placed to receive at least some of the materials (e.g. the treated sludge or effluent) produced by a previous reactor etc, whether directly or indirectly (e.g. one or more further reactors may be placed between the downstream reactor and the originating reactor).

When used herein, "upstream" means that a particular reactor etc is placed to provide at least some of the materials (e.g. the treated sludge or effluent) it has produced to another reactor etc, whether directly or indirectly (e.g. one or more further reactors may be placed between the upstream reactor and the another reactor).

When used herein, the term "inhibitor" means a metabolite(s) of the acidogenic reactor system or a supplied chemical(s) to said system. In embodiments, the metabolite(s) and/or the supplied chemical(s) are volatile fatty acids and/or  $H_2$ .

A two-phase anaerobic system produces two separate biogas streams, with the leading stream from acidogenesis essentially comprising  $CO_2$ . However, complete phase separation of the acidogenic and methanogenic phases has not yet been achieved, meaning that the gas from the acidogenic phase contains a little  $CH_4$  (< 20%). Traditionally, it has been argued that this  $CH_4$  is produced by methanogens that are largely similar to those in the methanogenic phase, but which have managed to survive in the acidogenic phase in small amounts because of unintended biofilms in the reactors and by re-inoculation from feed or

return biomass to the acidogenic reactor. It is believed that such biofilms offer some protection to the methanogens in the acidogenesis phase.

The inventors of the current invention have found that the above mechanism of methane generation in the acidogenesis need not be the only mechanism. This is because the inventors noticed that their acidogenic reactors consistently produced more CH<sub>4</sub> than expected and that volatile fatty acid production had also been improved. This suggested that the reactors were utilising processes that went beyond acidogenesis alone, especially because the reactors had been cleaned to reduce any incidence of biofilms, the feed was not fermenting and no biomass had been returned to the acidogenesis reactor.

In the current invention, the operating protocol designed for use on the acidogenic reactor is different from conventional approaches because it includes an inhibitor. Examples of inhibitors include, but are not limited to volatile fatty acids (VFAs) and H<sub>2</sub>.

VFA and/or H<sub>2</sub> can be produced *in-situ* or can be added to the acidogenic reactor. The concentration of VFA and/or H<sub>2</sub> are important, as these compounds are used to enhance the dominance of a particular group of Archaea (hydrogentrophic Archaea). However, very high concentrations of VFA and/or H<sub>2</sub> can inhibit all of the microbial population. In embodiments, a content of H<sub>2</sub> in biogas of from 20 to 40% can be used to suppress bacteria and enrich hydrogentrophic Archaea. Under this concentration of H<sub>2</sub>, VFAs will accumulate in the reactor system to further enhance the enrichment of the desired hydrogentrophic Archaea. Therefore, VFAs can also be used as an inhibitor, or regulator, too. In further embodiments, a VFA concentration of 3000 mg/L or above has a similar effect to H<sub>2</sub> on bacteria and hydrogentrophic Archaea in an acidogenic reactor. As noted above, VFA and H<sub>2</sub> can be generated *in-situ* or supplied to the reactor in a supplementary stream if necessary. In embodiments the VFA inhibitory strategy and the H<sub>2</sub> inhibitory strategy can be applied alone or in combination with each other.

The use of such inhibitors results in a microbial consortium that includes a high proportion of the Archaea group and *homoacetogenesis* group of microbes. Without wishing to be bound by theory, it is thought that the CO<sub>2</sub> is reduced by H<sub>2</sub> which is also formed in the same process. The reduction product of CO<sub>2</sub> then generates CH<sub>4</sub> and volatile fatty acids. Therefore, the system and method of the current invention allows recovery of CO<sub>2</sub> as CH<sub>4</sub> and as easily degradable carbon sources (VFAs) and thereby increases the calorific value of

the biogas generated in the acidogenic phase, as well as the food source for the following methanogenic process.

In addition, the currently claimed invention enhances the production of  $\text{CH}_4$  in the current method by recycling the produced biogas, thereby ensuring maximal conversion of the biogas into  $\text{CH}_4$  in the acidogenesis reactor (to greater than 20%  $\text{CH}_4$ , which is the limit of such conventional systems). Further, the production of  $\text{CH}_4$  is enhanced by controlling the concentrations of metabolites, such as  $\text{H}_2$  as described above. Following which, additional  $\text{CH}_4$  is produced in the downstream methanogenesis and/or anaerobic reactor.

As will be appreciated, the method described herein does not necessarily attempt to separate the  $\text{CO}_2$  from  $\text{CH}_4$ , but it biologically converts  $\text{CO}_2$  into more  $\text{CH}_4$  and volatile fatty acids by the co-existence of *Archaea* and bacteria. This adds to the calorific value of the biogas and represents a recovery of carbon that would otherwise have been lost. In further embodiments, the current system and method may be used together with downstream reactors to achieve additional forms of carbon recovery.

The current invention inserts a modified acidogenesis phase (i.e. a modified acidogenesis reactor) ahead of a typical single stage anaerobic reactor or a methanogenesis reactor (e.g. a methanogenesis reactor). Through a combination of start-up and operating conditions, the modified acidogenesis reactor allows culture and accumulation of a microbial consortium which has higher than usual numbers of hydrogenotrophic methanogens. This is described in more detail in the working embodiment below.

### Working Example

- a A two-phase anaerobic process is set-up and is equipped with pH, oxidation reduction process (ORP) and temperature controllers. The pH is controlled at 5.0-5.5 and temperature is maintained at  $40 \pm 1^\circ\text{C}$ . The ORP is about -400 mV. A Sequential batch system is operated with hydraulic retention time (HRT) 1.25-5 days, and solids retention time (SRT) 10-25 days.
- b Biogas is recycled in the acidogenic reactor aiming to (i) enhance the contact between microbes and  $\text{CO}_2$ , which therefore improves  $\text{CO}_2$  capture and  $\text{CH}_4$  production; and (ii) improve the mixing mechanism of the system in order to promote the desired reaction kinetics.

- c After a period of acclimation, the reactor's microbial community is expected to include about 90% Eubacteria and 10% Archaea. Hydrogentrophic methanogens including *Methanobacteriales* (MBT) and *Methanomicrobiales* (MMB), become highly dominant in the acidogenic reactor in the relative absence of *aceticlastic* methanogens.
- d The pathway of CO<sub>2</sub> reduction from H<sub>2</sub> to CH<sub>4</sub> is described in Fig. 1. In general, 1 mole of CO<sub>2</sub> requires 4 moles H<sub>2</sub> to produce 1 mole of CH<sub>4</sub> (-135.6 kJ/mol). The CO<sub>2</sub> reduction pathway includes two stages. Firstly, CO<sub>2</sub> is reduced to methyl-tetra-hydromethanopterin (CH<sub>3</sub>-H<sub>4</sub>M(S)PT) by CO<sub>2</sub>-reducing species via an enzyme system that includes coenzyme F420-dependent formate dehydrogenase and hydrogenase. The reactions transforming CH<sub>3</sub>-H<sub>4</sub>M(S)PT to CH<sub>4</sub> are catalyzed by coenzyme M(HS-CoM) and coenzyme B(HS-CoB) H<sub>4</sub>MPT. These reactions are common to both the *aceticlastic* pathway and the CO<sub>2</sub> reduction pathway.

In the process above, the concentration level of the inhibitor produced by the acidogenic reactor is highly dependent upon the feedstocks that are supplied to the treatment system. If the H<sub>2</sub> content in the biogas produced *in-situ* is from 20 to 40% and/or if the concentration of the VFAs produced *in-situ* is 3000 mg/L or above then it is not necessary to supply an additional amount of these inhibitors. However, in a situation where the feedstock does not reach the required inhibitory level once the system has reached a stable level of VFA and H<sub>2</sub> production, a supplementary amount of VFAs and/or H<sub>2</sub> can be added.

H<sub>2</sub> is produced and consumed simultaneously by different microorganisms in the acidogenic reactor. Both high concentrations of H<sub>2</sub> and VFA will inhibit acidogen (not methanogen) to obtain the desired microbial population. The fall of H<sub>2</sub> observed is caused by CO<sub>2</sub> captured. The peak/concentration of H<sub>2</sub> in Fig. 2 is designed to obtain the required population at the start-up stage. However, such a high content of H<sub>2</sub> can inhibit CO<sub>2</sub> capture process. Therefore, H<sub>2</sub> should be removed in a short time period. At the same time, VFA concentration will increase to help maintain the desired population.

In the acidogenic phase, the primary objective is conversion of biodegradable organics to volatile fatty acids (VFAs). The acidogens, responsible for VFA conversion, are predominant in acidogenic sludge which includes the following.

- (1) fermentative bacteria which are responsible for the VFA production;
- (2) hydrogen producing acetogenic bacteria which metabolizes propionic acid and other VFA, alcohol into acetate and  $H_2$ ; and
- (3) homoacetogen which are  $H_2$  and  $CO_2$  user to produce acetate.

The above mentioned populations perform well using the designated operating parameters to produce feed for a downstream unit, such units being a typical single stage anaerobic reactor or a methanogenesis reactor.

In the current invention, the other important group in the acidogenic reactor is a  $H_2$ -consuming methanogen (of the *Archaea* group) which also reduces  $CO_2$  by  $H_2$ , but to produce  $CH_4$ . This normally takes place in the ordinary methanogenesis phase in the subsequent methanogenesis tank (or in combination in an anaerobic tank where the pH of the reactor is controlled). However, this  $H_2$ -consuming methanogen also exists in the acidogenic stage because of the symbiotic relationship between the hydrogen producing bacteria and the hydrogen consuming methanogen even with a pH between 5.0 and 5.5, which is lower than that normally tolerated by methanogenic microbes. This enables the production of  $CH_4$  by sequestering  $CO_2$  from the biogas produced in the acidogenic phase. In the methanogenic phase, VFAs produced in acidogenic phase are further consumed to produce methane. Therefore, the current invention ensures that the amount of  $CO_2$  that eventually produced by the current system is reduced as much as possible, which maximises the calorific value of the produced biogas.

The concept of converting " $CO_2$  to  $CH_4$ " during the acidogenic phase was further supported by the data collected from the two-phase lab-scale system described above.

First, the biogas content varied before and after gas recycling during the acidogenic stage (Fig. 2). Originally, the main gas contents were  $CO_2$  (about 75 %) and  $H_2$  (20 %) with a  $CH_4$  content of from 5-10%. However, after the gas recycling strategy was applied, the  $CH_4$  content increased gradually to about 40% while the  $CO_2$  content of the acidogenesis stage decreased from 75% to 55% and  $H_2$  content decreased from 20% to 0%. This means that the acidogenesis reactor alone can achieve methane conversion similar to that achieved in a fully-fledged anaerobic reactor or two-stage reactor, before the material that is left is sent to

the methanogenesis reactor for further conversion to methane (e.g. conversion of the VFAs to methane, as described above).

Therefore, as shown by the example above, the  $H_2$ -consuming bacteria helps to lower the concentration of  $H_2$  below the inhibitory level so that propionate degrading bacteria are not suppressed by an excessive level of  $H_2$ , which thereby shows a symbiotic and synergistic effect. The change of biogas content indicates that  $CO_2$  and  $H_2$  were consumed by the hydrogenotrophic methanogen included in the current system and that the ultimate product of this consumption was  $CH_4$  during the acidogenic phase. At the same time the VFA conversion was also improved (data not shown) and become greater than or equal to 3000 mg/L.

The results discussed above show that the gas recycling strategy adopted herein enhanced both  $CH_4$  production and VFA conversion.

In addition, the microbial community composition of the acidogenic sludge was analyzed by fluorescent in-situ hybridization (FISH) (Fig. 3) and real time polymerase chain reaction (qPCR) (Fig. 4) to detect the specific microorganisms present. In Fig. 3, lighter coloured stains show the *Archaea* group (methanogen was part of *Archaea*) and the darker stains show all of the other microorganisms. This indicates that *Archaea* and the other bacteria were symbiotic, which is beneficial to  $CH_4$  production.

Further, the ratio of hydrogen-trophic and acetic-trophic methanogen was quantified by qPCR (Fig. 4). MBT (*Methanobacteriales*) and MMB (*Methanomicrobiales*) are known to be hydrogenotrophic methanogens that use  $H_2/CO_2$  to synthesize methane while MST and MSC are acetotrophic methanogens that are capable to use acetate to synthesize methane. The acidogenic reactor was started with anaerobic sludge as seed from an existing anaerobic system. During 140 days operation, the acetotrophic methanogens decreased while hydrogenotrophic methanogen was enriched at pH 5.0. This made it possible to enhance  $CH_4$  production in acidogenic phase by gas recycling.

It will be appreciated that the currently described process results in additional  $CO_2$  capture and energy recovery from different feeds, such as wastewater and sludge in an acidogenic reactor where the bacterial populations have been modified by careful control of inhibitors. Transferral of the remaining sludge/effluent from the acidogenic reactor described herein to a downstream reactor (e.g. a methanogenic reactor) is achieved by conventional means.

The currently disclosed invention is expected to have applications in wastewater treatment with energy reduction and recovery. The latter is of growing importance given the growing awareness of the energy-environment nexus. Current state-of-the-art wastewater treatment has a significant carbon footprint and this invention is a move towards energy neutral and, eventually, energy positive treatment facilities. The invention can be used in both sewage and industrial wastewater treatment, at new plants and as a retrofit addition to existing facilities. In the retrofit scenario, the addition of this invention can also serve to expand the treatment capacity of the existing facility and hence avoiding need for expansion of existing treatment facilities as needs increase.

**CLAIMS**

1. An acidogenic reactor system for use in a wastewater treatment plant, said system comprising an inhibitor, wherein the inhibitor is one or more volatile fatty acids and/or H<sub>2</sub> that is capable of regulating a microbial population and wherein the reactor system further comprises an acidogenic sludge comprising a microbial community of 90% Eubacteria and 10% *Archaea*.
2. The acidogenic reactor system of Claim 1, wherein:
  - the concentration of H<sub>2</sub> in the reactor is from 20 to 40%; and/or
  - the concentration of the one or more volatile fatty acids is greater than or equal to 3000 mg/L.
3. The acidogenic reactor of Claim 1, wherein the concentration of H<sub>2</sub> and/or the concentration of the one or more volatile fatty acids is wholly generated *in situ* by a microbial population within the acidogenic sludge or is partly generated *in situ* by the microbial population and partly supplied by a supplementary stream of H<sub>2</sub> and/or one or more volatile fatty acids.
4. The acidogenic reactor of Claim 3, wherein the concentration of H<sub>2</sub> and/or the concentration of the one or more volatile fatty acids is partly generated *in situ* by a microbial population within the acidogenic sludge and partly supplied by a supplementary stream of H<sub>2</sub> and/or one or more volatile fatty acids.
5. The acidogenic reactor system of Claim 1, wherein the microbial community comprises:
  - fermentative bacteria;
  - hydrogen producing acetogenic bacteria;
  - homoacetogens; and
  - one or more H<sub>2</sub>-consuming methanogens of the *Archaea* group.
6. The acidogenic reactor system of Claim 5, wherein the one or more H<sub>2</sub>-consuming methanogens of the *Archaea* group are capable of functioning in an acidic environment.

7. The acidogenic reactor system of Claim 6, wherein the one or more H<sub>2</sub>-consuming methanogens of the *Archaea group* comprise *Methanobacteriales* (MBT) and/or *Methanomicrobiales* (MMB).
8. The acidogenic reactor system of any preceding claim, wherein the reactor system is substantially or wholly free of biofilms.
9. The acidogenic reactor system of any preceding claim, wherein the wastewater treatment plant is a sewage plant or an industrial wastewater plant.
10. The acidogenic reactor system of any preceding claim, wherein the acidogenic reactor system is fitted upstream of a one-stage anaerobic reactor or a methanogenic reactor.
11. The acidogenic reactor system of any Claim 10, wherein the acidogenic reactor system is fitted upstream of a methanogenic reactor.
12. The acidogenic reactor system of any preceding claim, wherein the acidogenic reactor system further comprises an apparatus for recycling biogas produced by the acidogenic reactor system back into said acidogenic reactor system.
13. The acidogenic reactor system of any preceding claim, further comprising pH, oxidation reduction potential (ORP) and temperature controllers.
14. A method of generating biogas using an acidogenic reactor system, said method comprising the steps of:
  - (i) seeding the acidogenic reactor with anaerobic sludge as seed from an existing anaerobic system;
  - (ii) adding anaerobic sludge to the acidogenic reactor in a sequential batchwise or a continuous manner;
  - (iii) maintaining a pH range within the acidogenic reactor of 5.0-5.5 and a temperature between 30 and 50°C;
  - (iv) manipulating the concentration of an inhibitor in the acidogenic reactor to regulate the microbial population, where the inhibitor is selected from one or more volatile fatty acids and/or H<sub>2</sub>;
  - (v) optionally recycling the biogas produced within the acidogenic reactor to the acidogenic reactor for further reaction;

- (vi) transferring the treated anaerobic sludge to a downstream reactor of the one-stage anaerobic type or of the methanogenic type; and
- (vii) repeating steps (iii) to (vi).

15. The method of Claim 14, wherein in step (v):

the concentration of  $H_2$  in the gaseous phase of the acidogenic reactor is from 20 to 40%; and/or

the concentration of the one or more volatile fatty acids is greater than or equal to 3000 mg/L.

16. The method of Claim 15, wherein the concentration of  $H_2$  in the gaseous phase of the acidogenic reactor reaches a peak level of from 20 to 40% during the start-up phase of the reactor and drops to from 0% to less than 20% thereafter; and

wherein the concentration of the one or more volatile fatty acids is greater than or equal to 3000 mg/L is achieved as the concentration of  $H_2$  starts to drop from its peak level.

17. The method of any one of Claims 14 to 16, wherein the ORP of the acidogenic reactor is about -400 mV and the temperature is  $40 \pm 1^\circ\text{C}$ .

18. The method of any one of Claims 14 to 17, wherein the hydraulic retention time (HRT) is 1.25-5 days, and the solids retention time (SRT) is 10-25 days.

19. The method of any one of Claims 14 to 18, wherein preceding step (i) the acidogenic reactor is cleaned to substantially or wholly remove biofilms.

20. Use of volatile fatty acids (VFAs) and  $H_2$  to regulate the microbial population of an acidogenic reaction, wherein the use comprises a reaction in an acidogenic reactor and:

the concentration of  $H_2$  in the gaseous phase of the reactor reaches a peak level of from 20 to 40% during the start-up phase of the reactor and drops to from 0% to less than 20% thereafter; and

the concentration of the one or more volatile fatty acids is greater than or equal to 3000 mg/L is achieved as the concentration of  $H_2$  starts to drop from its peak level.