Washington State University

Center for Sustaining Agriculture and Natural Resources

Advanced small-scale anaerobic digester design tailored for household user living in cold climate

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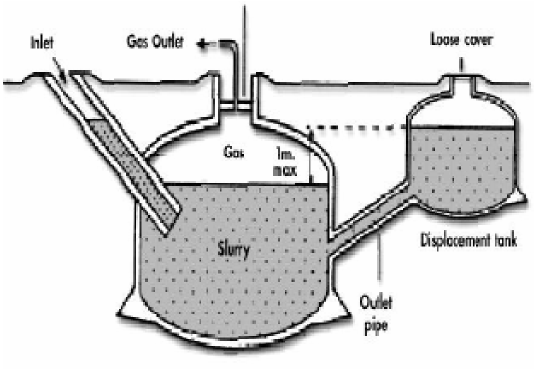
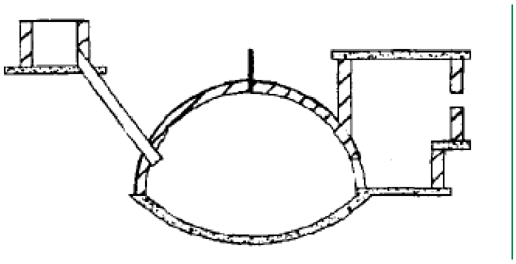
ABSTRACT

A design of small-scale anaerobic digester is invented to stabilized and convert household livestock manures and crop wastes into biogas in cold climate area. The design includes a column fermentation chamber with arc baffle and slope on the bottom and a domed biogas chamber on the top, a hydrolysis chamber in connection with the influent and effluent chambers, and back valves as well as biogas outlet. The construction of the disclosed small digester is suggested to be in greenhouse beneath the frost depth for temperature preservation. An automatic broth recirculation mechanics is realized through the pressure changes with intermittent biogas generation and usage, which not only creates the mixing effect but also bring along continous inoculation. Stalk materials are separately liquefied in a dedicated hydrolysis chamber to prevent clogging risk. The arc baffle and slope floor are particularly designed to prevent short-circuit and ensure smooth desludge. High specific surface inner wall structure is also devised to retain fermentative microbial in the form of biofilm. This advanced small digester design fixes a series of intrinsic problems in terms of heating, mixing, inoculation, clogging, crustation and stalk digestion that have hampered the conventional small digesters application.



A



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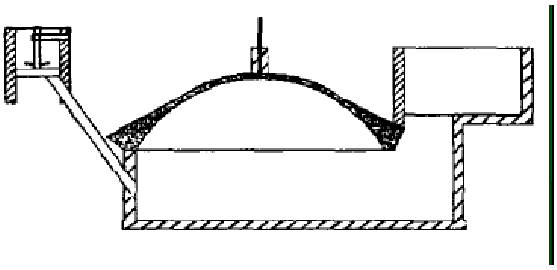

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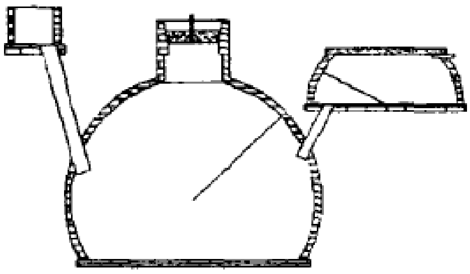


D

Figure 1

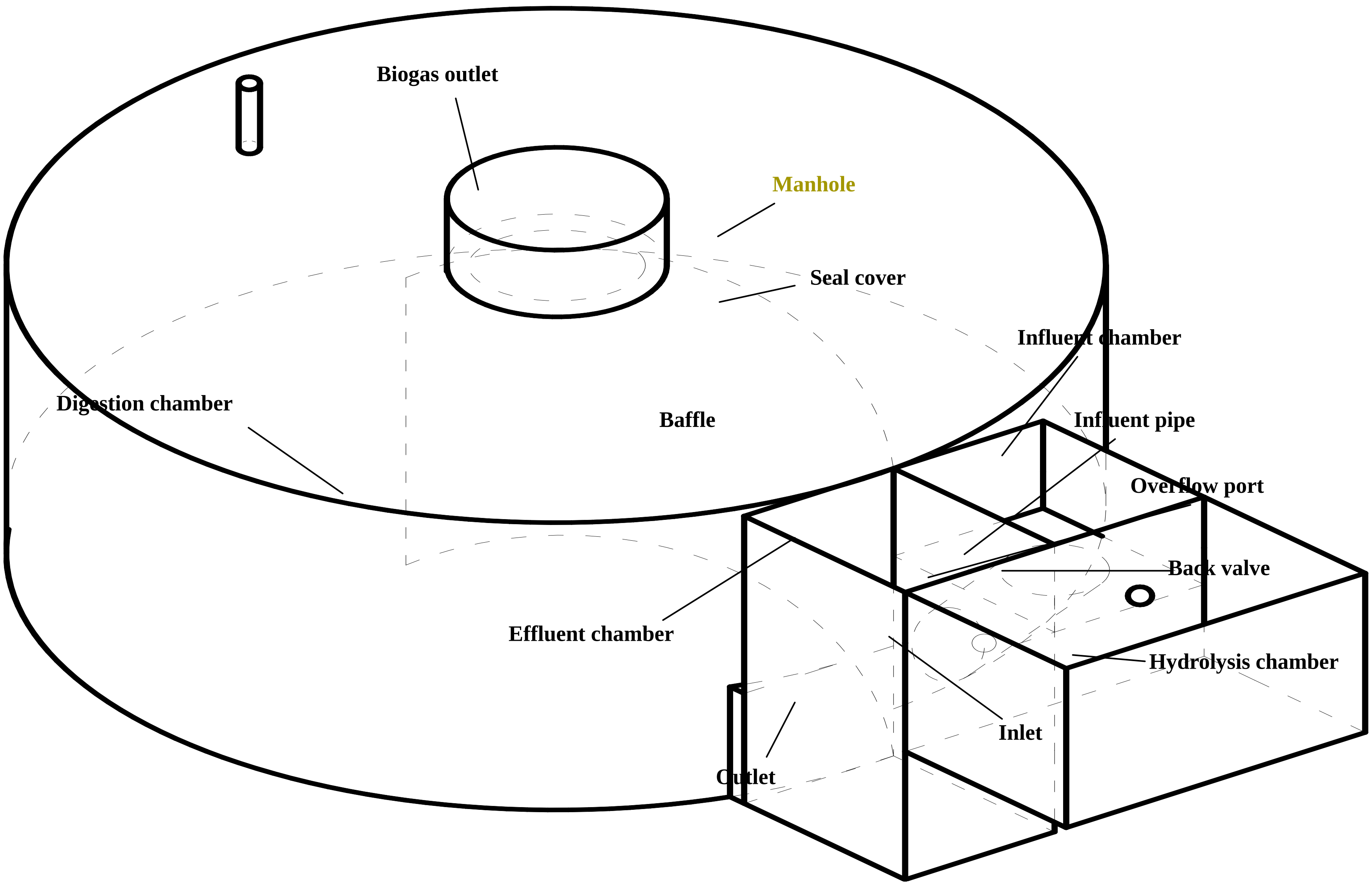
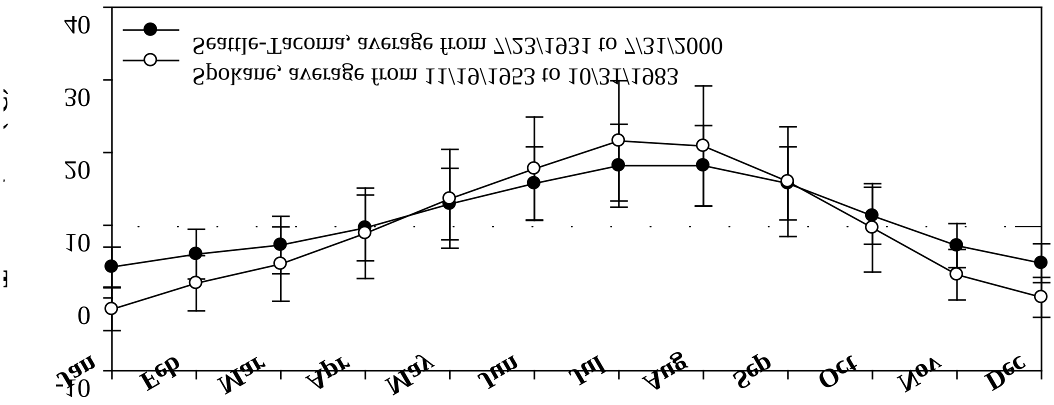

Biogas outlet
Manhole
Seal cover
Influent chamber
Digestion chamber
Baffle
Influent pipe
Overflow port
Back valve
Effluent chamber
Hydrolysis chamber
Inlet
Outlet

Figure 2


Seattle-Tacoma, average from 7/23/1931 to 7/31/2000
Spokane, average from 11/19/1953 to 10/31/1983
40
30
20
10
0
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Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Figure 3

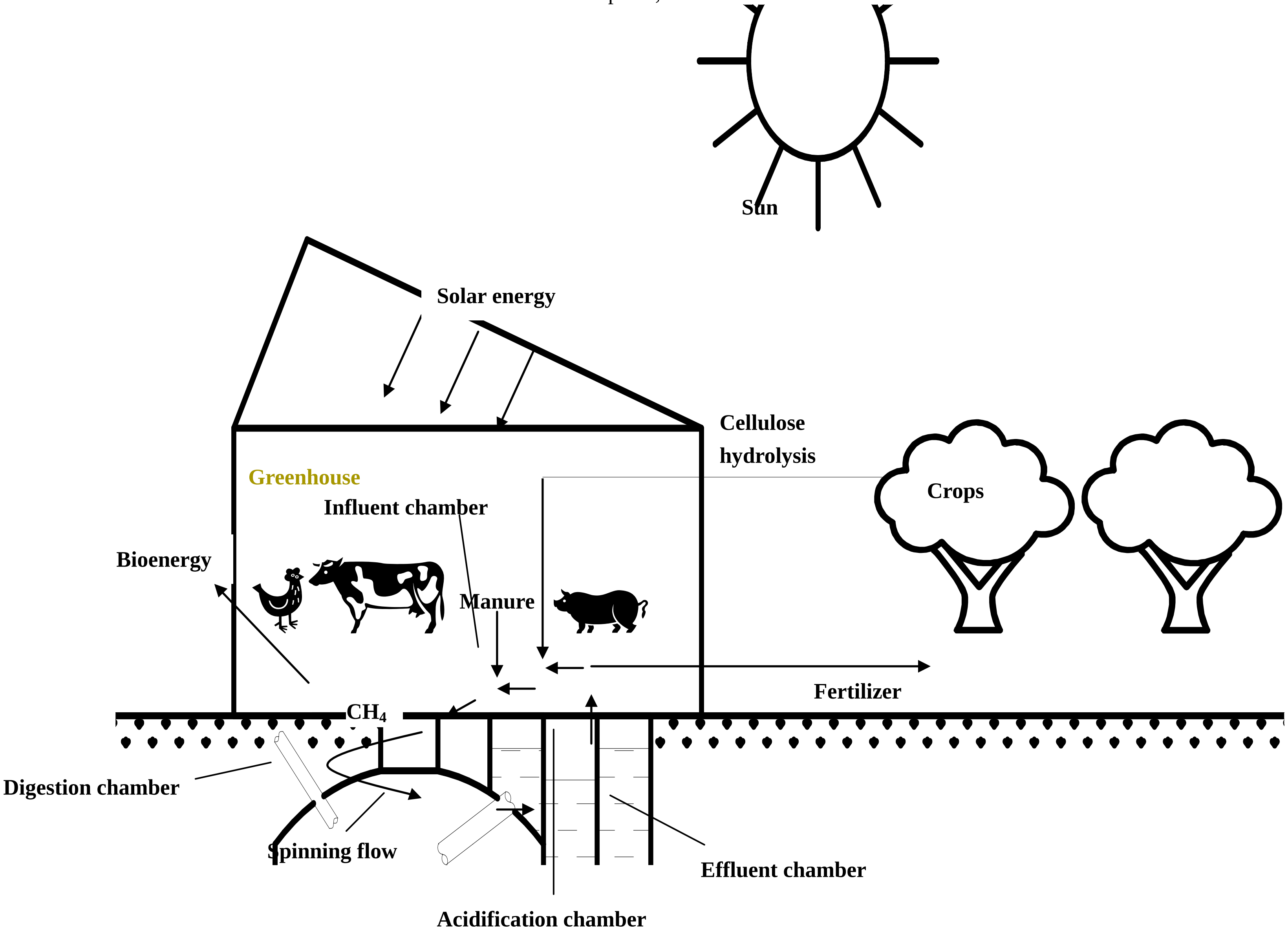
Sun
Solar energy
Cellulose
hydrolysis
Greenhouse
Influent chamber
Crops
Bioenergy
Manure
Fertilizer
CH4
Digestion chamber
Spinning flow
Effluent chamber
Acidification chamber

Figure 4

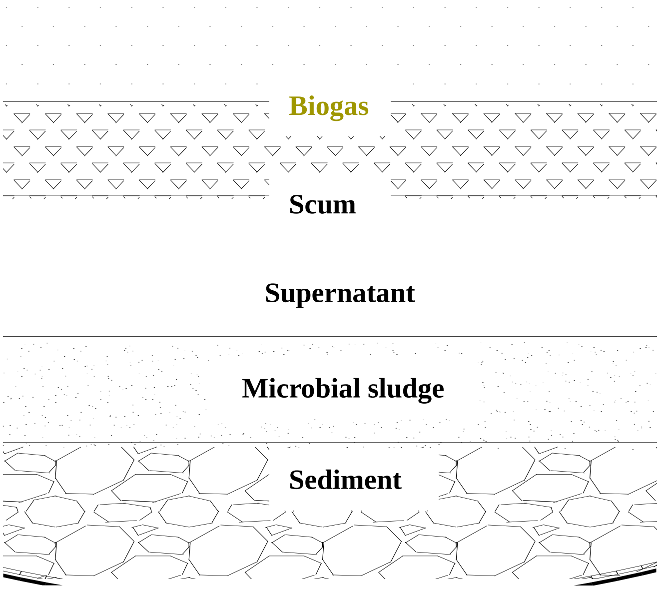

Figure 5

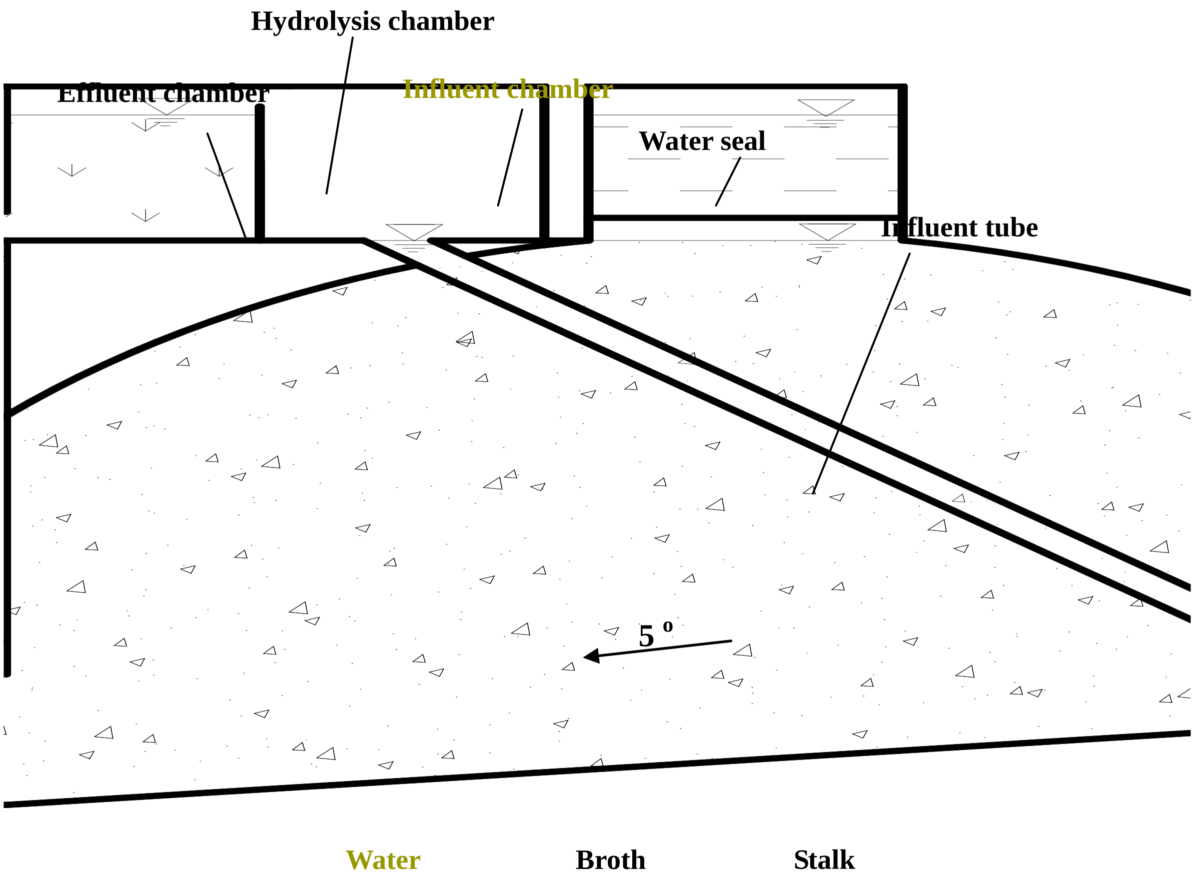
Hydrolysis chamber
Effluent chamber
Influent chamber
Water seal
Influent tube
5 o
Water
Broth
Stalk

Figure 6

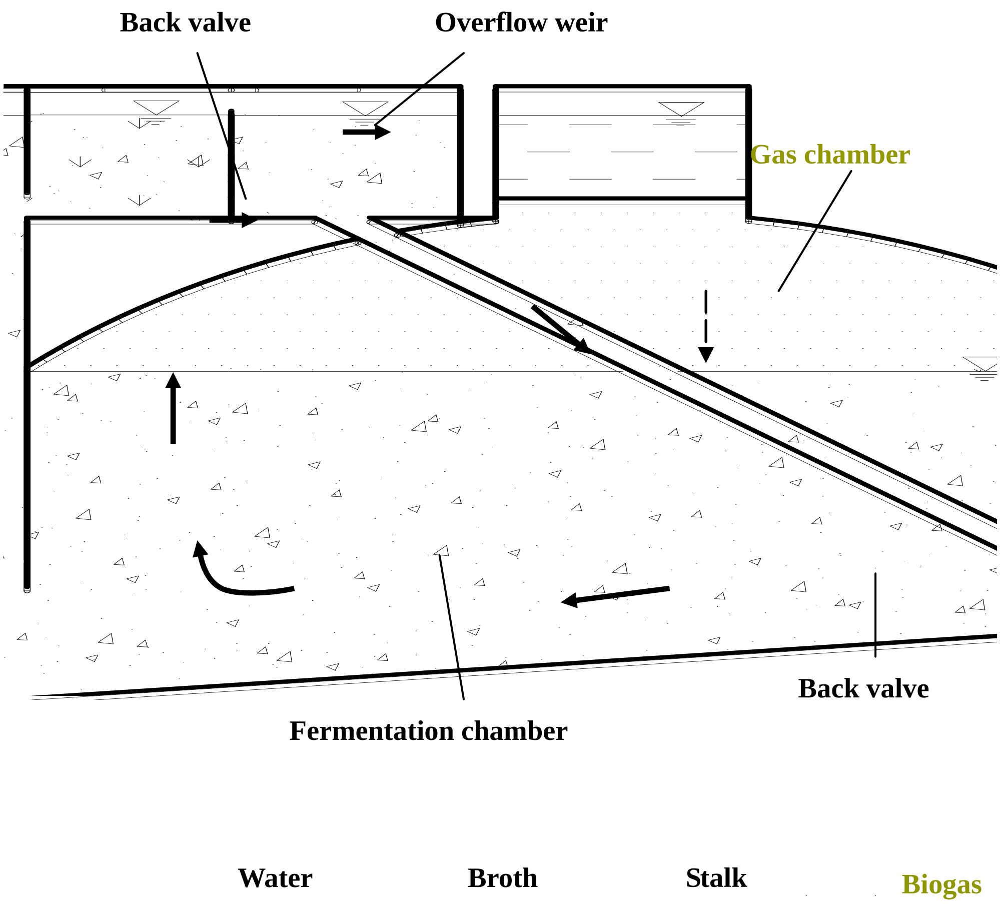
Back valve
Overflow weir
Gas chamber
Back valve
Fermentation chamber
Water
Broth
Stalk
Biogas

Figure 7

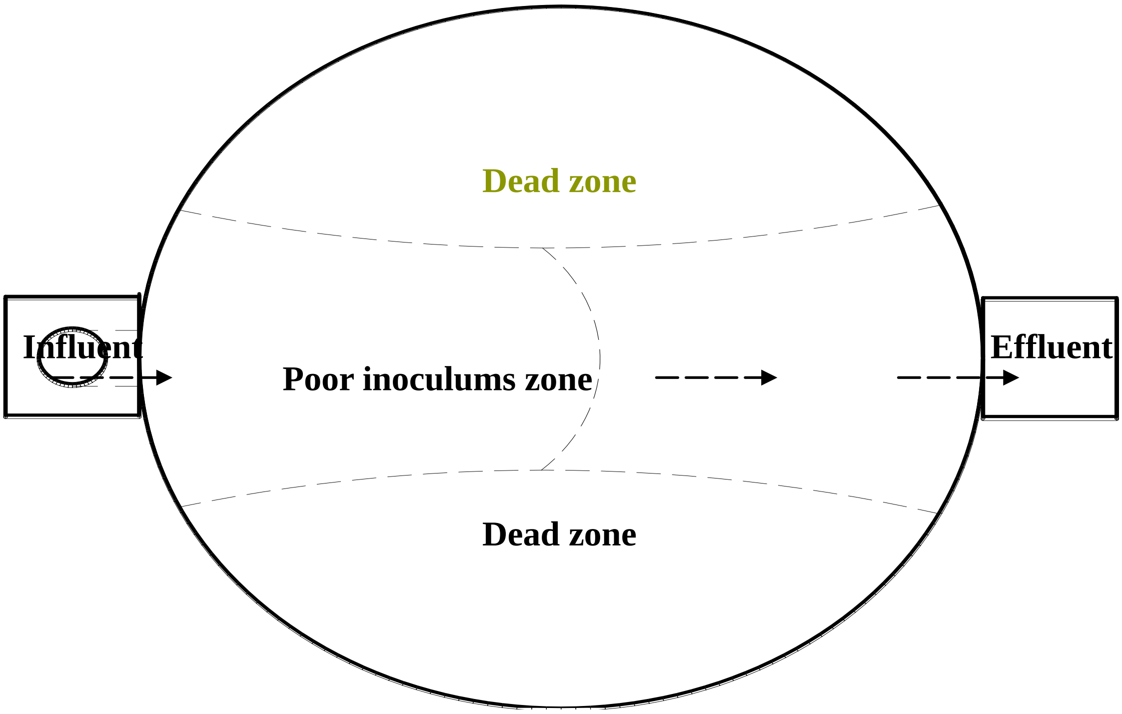

Figure 8

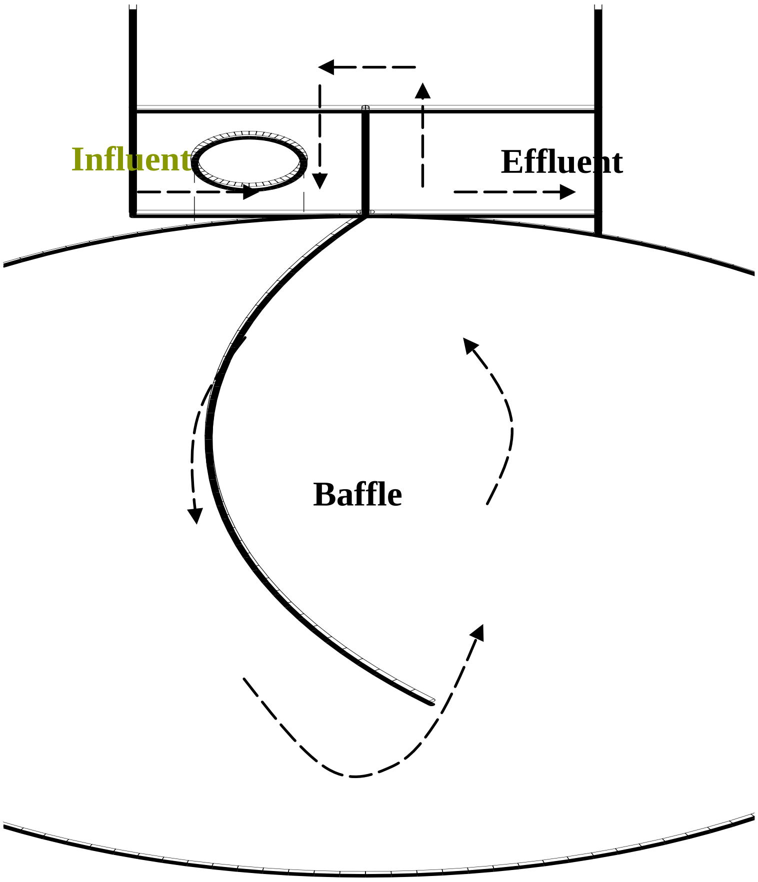

Figure 9

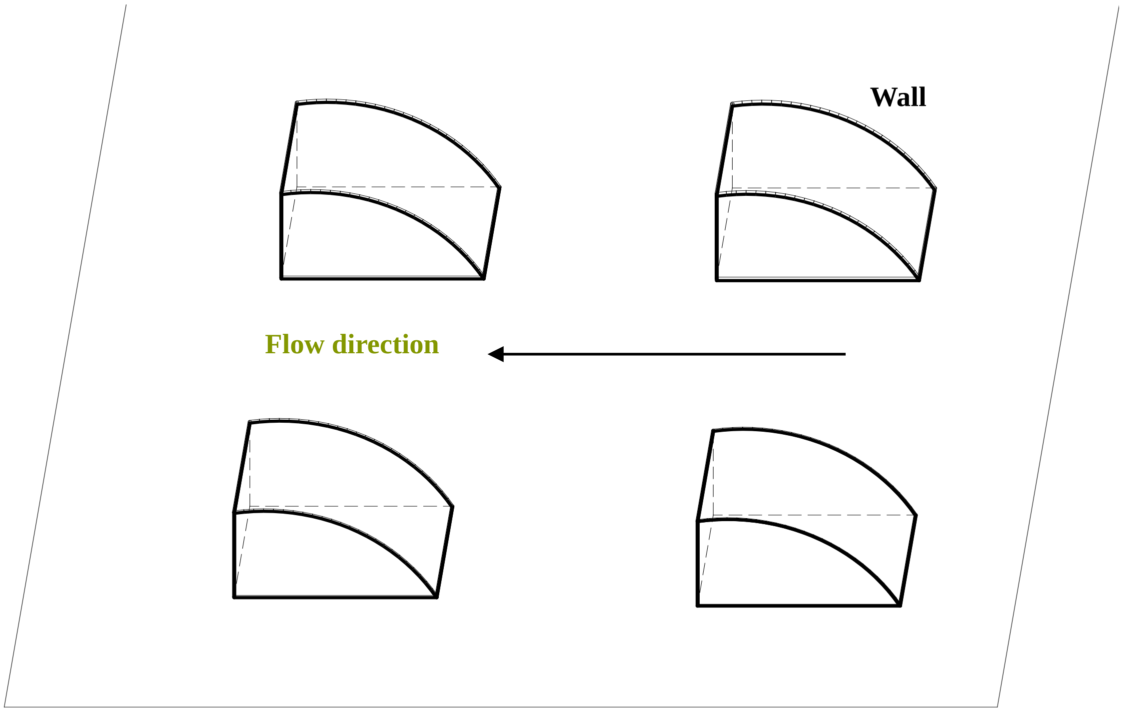

Figure 10

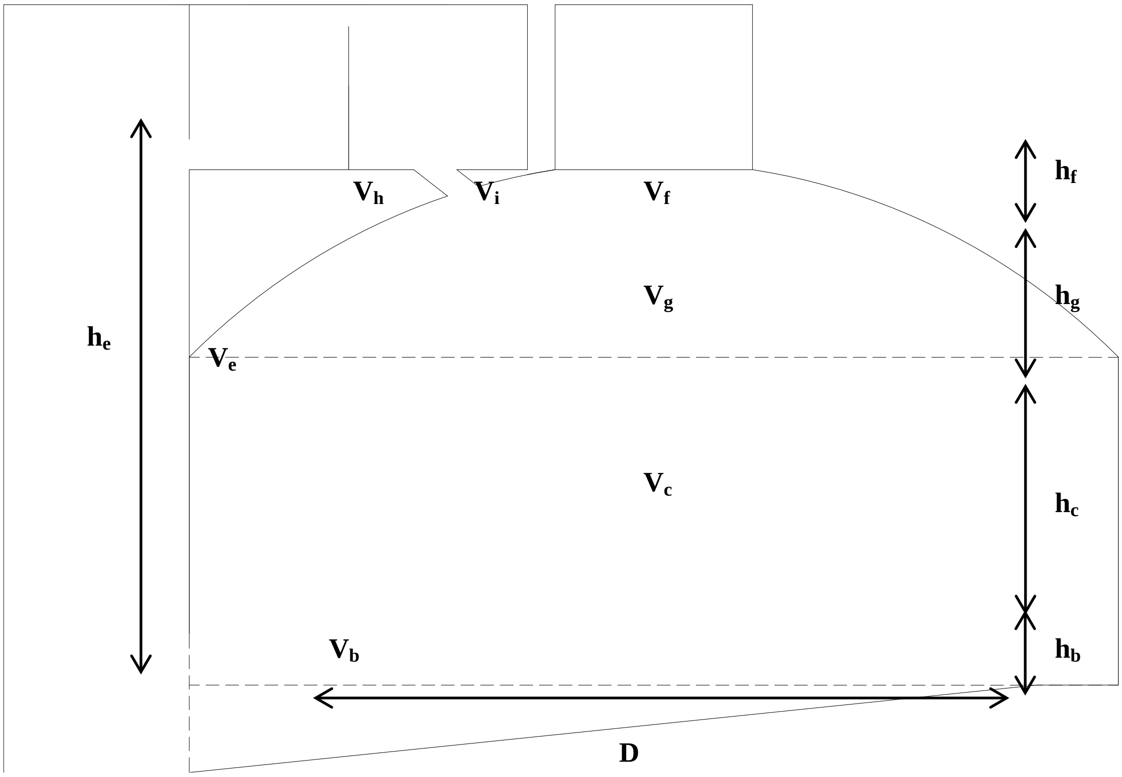

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Figure 11

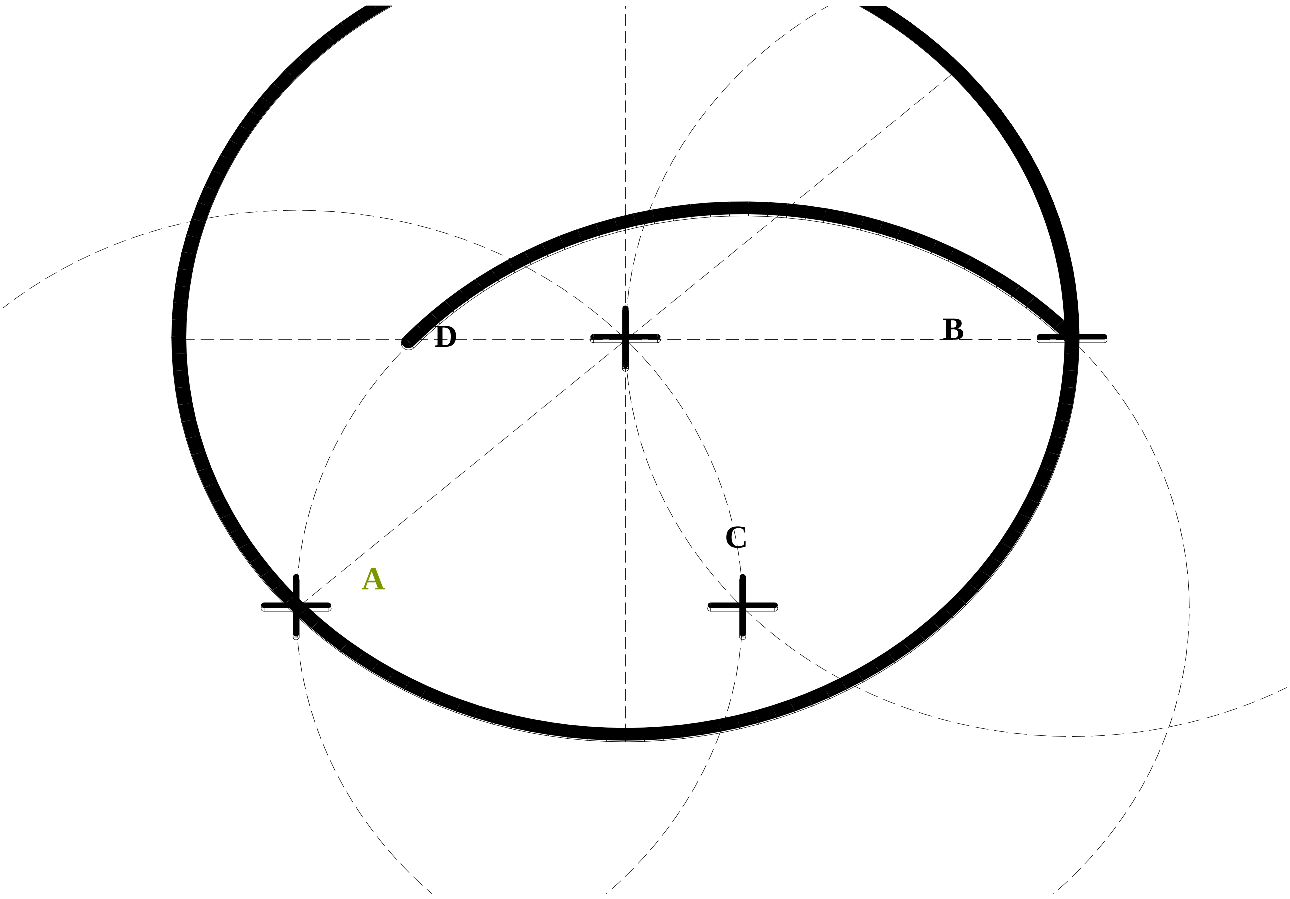
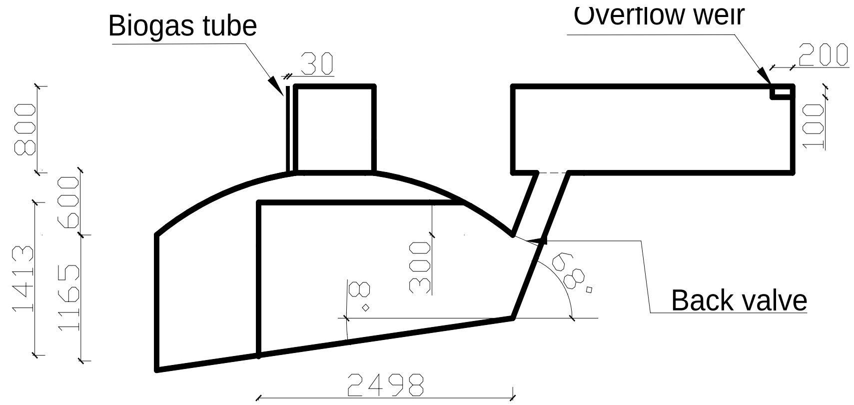
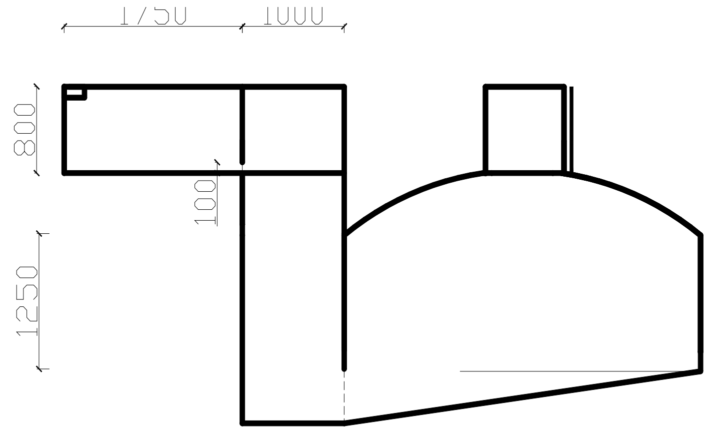


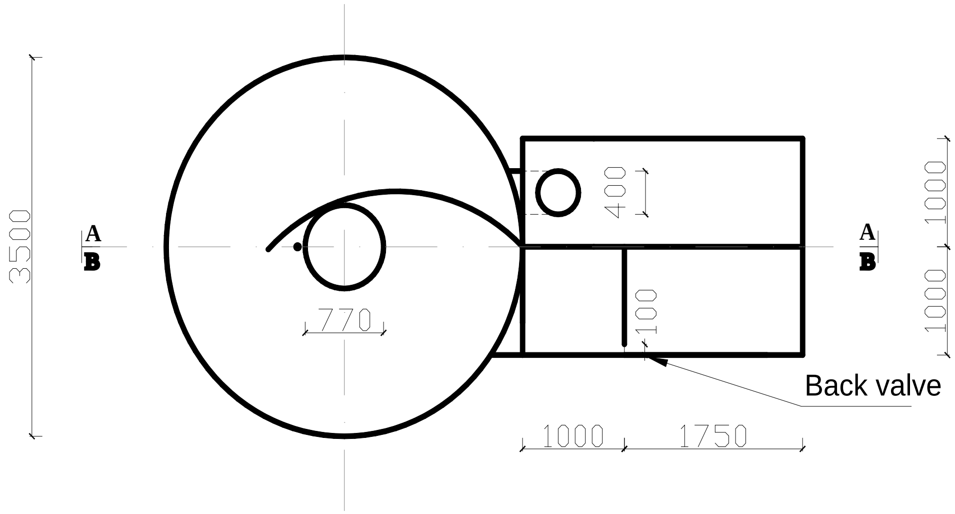
Figure 12



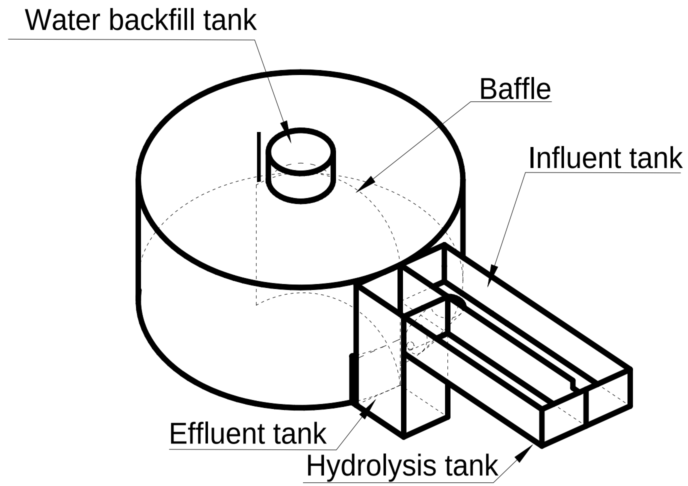
Section A-A



Section B-B



Top view of the digester



3-D view of the digester

Figure 13

INVENTION HIGHLIGHTS

1. A greenhouse and underground construction based strategy is proposed to preserve small-scale digester temperature in cold climate.

2. A fermentation broth auto-recirculation mechanics is designed to introduce mixing and continuous inoculation with zero energy input

3. A high specific inner digester wall structure is designed to retain biomass

4. An arc baffle is specially designed to prevent influent short-circuit and dead zones formation

5. A hydrolysis chamber especially tailored for degradation of stalk materials separately from animal manure so as to avoid inner digester clogging

6. A slopefloor is designed to facilitate smooth desludge in cooperation with fermentation broth auto-recirculation mechanics

7. The arc baffle height is designed in such a way to crush any crust formed at water/liquid interface

BACKGROUND OF THE INVENTION

Biogas digester offers an all-in-one means to meet multi-environmental and economic requirements such as greenhouse gas reduction, renewable energy generation, organic wastes stabilization, odor elimination, pathogen removal and organic fertilizer production. In terms of application goal and scale, biogas digester can be categorized into two types, i.e. small-scale and medium/large-scale biogas digesters. The small-scale digester always has a limited working volume lower than 50 m^3 and serves primarily for household heating and cooking energy generation; in comparison, medium/large-scale biogas digesters are designed for industrial and municipal organic wastes treatment with COD/BOD reduction as a primary purpose and biogas production as a tipping fee. In contrast to the intensive research and development of medium/large scale biogas digester for decades, the importance of small scale one has been largely ignored. While, along with the fossil energy stringency in recent years, the benefit of applying small-scale digester to meet household energy requirement in the course of household wastes stabilization and organic fertilizer production has stepped into the vision of modern farmer families.

As a matter of fact, small-scale digester has been broadly used as economical energy provider for household farmers in developing countries for decades. Figure 1 presents several typical small-scale digesters designs broadly applied in China, India, Nepal and Vietnam, respectively. As can be seen, all of those small-scale digesters are actually following the same looking comprising a domed column digester body linked in between influent and effluent ports (Figure 1). Accordingly, feedstock is pushed in from one end, biogas is collected from dome, and digested sludge as well as extra fermentation broth is removed from the other end of the digester. These analogies can be attributed to the common needs for household from different countries. Household users always desire their digesters to be small, simple and economical. The small digesters in Figure 1 are all under the volume of 50 m^3 and their construction costs are less than 150 US$ without external energy input but enough biogas output for adjacent household usage. However, the over simplicity in these digesters in Figure 1 also incurs annoying problems to household users. For cost-effectiveness concern, they are lack of heating and mixing mechanisms that are often compulsory in medium/large scale digesters, which result in slow biogas productivity and severe mass transfer limitations. Furthermore, congestion and crustation are also main factors causing a digester to be abandoned at a short lifetime. For this regard, this invention disclosure aims to provide a design capable of overcoming those conventional household digesters shortcomings while still keeping their benefits in terms of simplicity and economy. This disclosed design includes following advantages, i) a greenhouse temperature preserving strategy is taken to keep underground digester at high rate performance with no need of external energy input; ii) a biogas pressure driven fermentation broth auto-recirculation mechanics is exploited for the first time to realize mixing and inoculation in household digester with no extra system complexity; iii) a hydrolysis chamber is specially dedicated to separately hydrolyzing stalk materials from animal manure so as to avoid congestion and scum crustation problems; iv) a high surface inner digester wall is designed for high biomass retention in the form of biofilm; and v) a arc baffle is placed to prevent flow short-circuit. More importantly, detailed design guidelines are provided for potential users to fabricate such an advanced small digester.

BRIEF SUMMARY OF THE INVENTION

The subject invention provides a design and method for the efficient anaerobic digestion of household wastes in a small-scale anaerobic digester with simple configuration and no need of energy input.

It is a further object of the present invention to provide a closed system apparatus and method to separately digest crop wastes before mixing its hydrolysate with the animal manure in fermentation chamber.

It is still further object of the present invention to provide a closed system apparatus and method for methanation of livestock manure with solar energy in greenhouse in winter.

It is still further object of the present invention to install an arc baffle to prevent short-circuit and dead zones in small-scale anaerobic digester.

Further objects and advantages of the present invention will become apparent by reference to the following description of the preferred embodiment and appended drawings.

The present invention includes a column fermentation chamber, a domed gas chamber, influent and effluent chambers and a hydrolysis chamber. Animal manure and crop wastes are separately fed into the influent chamber and hydrolysis chamber, respectively. The biogas production and usage in the biogas chamber creates dynamic force driving automatic fermentation broth recirculation from effluent chamber into influent chamber. This recirculation also solves the poor inoculation problem in conventional small-digester design. This small-scale digester is proposed to be constructed beneath the frost depth under greenhouse floor.

In a specific embodiment, the digester includes an influent chamber that delivers collected animal manure through an influent tube to the bottom of fermentation chamber. A slope floor will facilitate the feedstock transport from influent to effluent ports along a specially designed arc baffle during the fermentation phase by gravity force or biogas pressure. The fermentation broth will be pressed by biogas pressure over the back valve from effluent chamber into hydrolysis chamber and then into the influent chamber to realize an auto-recirculation which brings hydrolysate produced in hydrolysis tank from straw materials and the rich inoculums accumulated in effluent chamber into fermentation chamber for enhanced biogas production. This auto-recirculation also breaks the layered mixed liquor structure in conventional household digester.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 Representative small-scale digesters currently being used in developing countries; A: China using fixed dome biogas digester in; B: India using Deenbandhu biogas digester; C: Nepal using GGC biogas digester; and Vietnan using KT1 biogas digester (Hu and Xia 2006).

Figure 2 3D view of the disclosed small scale digester

Figure 3 Historical monthly temperature profile in eastern and western Washington State represented by Seattle-Tacoma and Spokane, respectively

Figure 4 Illustrative concept for the small-scale digester application in cold climate area

Figure 5 Layered structure in non-mixing small-scale digester

Figure 6 Illustration for fermentation broth auto-recirculation mechanism before biogas production

Figure 7 Illustration for fermentation broth auto-recirculation mechanism after biogas production

Figure 8 Poor inoculums and dead zone problems in conventional anaerobic digester design

Figure 9 Poor inoculums and dead zone problems in conventional anaerobic digester design

Figure 10 Example protruding inner wall structures for microbial retention in digester

Figure 11 Illustrative dimensions for components consisting of small-scale digester

Figure 12 Method to determine the arc baffle location

Figure 13 Example drawing for the small scale digester

DETAILED DISCLOSURE OF THE INVENTION

Temperature is a crucial factor influencing the robustness of fermentative bacteria and thus the corresponding efficiency in solid wastes disintegration and methane gas production. The temperature for anaerobic digestion process can be categorized into three ranges, namely thermophilic (46 to 60 ^{o}C), mesophilic (28 to 38 ^{o}C) and psychrophilic (10 to 26 ^{o}C) anaerobic digestions. Theoretically, high temperature favors fast anaerobic bioreaction and according to Arrhenius equation, this anaerobic reaction rate will double for every 10 ^{o}C increase (Figure 4). It has been verified that hardly any methane gas can be produced when temperature gets lower than 10 ^{o}C.

In cold climate area in America such as Washington State, the environment temperature keeps below this minimum temperature required for anaerobic digestion for nearly six month a year (Figure 3). This means that heating measure has to be taken to keep digester at an appropriate temperature. Whereas, since the primary goal for a household digester is to generate heating energy in service for family, any additional heating power input should be the last choice. In this case, solar energy turns out to be a best option for farmers to utilize as an economical and effective resource to heat small digester to a suitable temperature. As a matter of fact, solar energy powered greenhouse has been used as a common practice for farmers living in cold area to carry on livestocks breeding and crops cultivation throughout the winter time. Therefore, those greenhouses also can be by the way utilized to keep small digester at a warm condition (Figure 4). Placing this small digester underneath the greenhouse floor offers convenience to feed livestocks and crops wastes in close distance in situ (Figure 4). It has been recognized that a stable temperature is crucial to keep the activity of methanogenic bacteria who is extremely sensitive to temperature fluctuation (Metcalf and Eddy 2003). Temperature changes greater than 1 ^{o}C d^{-1} has been found to affect digester performance, and thus changes less than 0.5 ^{o}C d^{-1} are more desirable (Metcalf and Eddy 2003). Underground construction offers an isolated environment free of surface air convection. Therefore, the disclosed small-scale digester should be constructed below the frost depth from the ground surface. Take the 0.8 m frost depth in Pullman, Washington state for example, the digester should be constructed beneath this depth to buffer any possible surface environment fluctuation within a narrow range (Figure 4).

Unlike the medium/large-scale digester, there is no mixing mechanics installed on conventional small-scale digesters owing to their simplicity requirement (Figure 1). As a consequence, fermentation broth always demonstrates a layered structure due to the settlement of feedstock mixture with different densities. Normally, five layers are presented in those lack of mixing digesters, distributed from top to the bottom in the order of biogas, scum, supernatant, activated sludge and sediments (Figure 5). This layered structure in digester content directly leads to the poor contact between fermenters in microbial sludge and the organic feedstock in the settlement layer, which in turn causes slow and incomplete anaerobic digestion. Moreover, the floating scum in the second layer tends to form crust on liquid surface because of the lack of mixing, which obstructs biogas release from the fermentation broth. Apparently, a mixing mechanics is necessary to be introduced into small digester for efficient biogas production.

A biogas pressure driven fermentation broth auto-recirculation stategy is disclosed in this invention to solve small digester mixing problem in an easy and economical way. As illustrated in Figure 6, prior to biogas production, equal fermentation broth level is distributed among digester and its influent as well as effluent chambers. Hydrolysis chamber owns a higher level in order to soak stalk materials for a prolonged cellulose solubilization phase. Water is backfilled on the top of the digester to provide balanced pressure against that of the biogas and also seal any possible gas leakage. Whenever there is biogas pressure established in fermentation chamber as a result of anaerobic digestion, the fermentation broth level in biogas chamber would be pushed downwards and in turn the level in the effluent chamber would be pushed upward over the back valve connecting with the hydrolysis chamber. Subsequently, the broth in hydrolysis chamber will overflow and fill up the influent chamber as illustrated in Figure 7. At this point, as soon as the biogas is used by household, the pressure in digester will drop and the broth levels in the influent chambers is going to flow back into digester. However, it should be noted that, because of the back valves installation, the broth that has been pressed into influent chambers has only one way to flow back into the digester, i.e. the tube connecting the influent chamber and digestion chamber (Figure 7). Thereby, a biogas driven fermentation broth auto-recirculation is realized. By extending the influent tube into the digester bottom at inlet, this fermentation broth recirculation design will be effective in preventing layered digester inner structure formation revealed in Figure 5.

Conventional small-scale anaerobic digester revealed in Figure 1 simply employs a one-way in and out design without consideration for inoculation. Consequently, a poor inoculums zone is formed right downstream to the influent port as shown in Figure 8. This implicates that fresh feedstock won't have chance to be contacted with fermentative bacteria and thus a limited fermentation rate is to be resulted in those digesters. The fermentation broth auto-recirculation design demonstrated in Figure 7 offers solution to such a problem by continuously bringing bacteria rich fermentation broth from the digester outlet back to inlet in contact with feedstock (Figure 7). This process is totally automatic together with the proceeding of biogas production and usage, and thus save the time and labor for manual inoculation as practiced if otherwise.

Since column structure is routinely used for small-scale digesters design by virtue of their good resistance to pressure, feedstock is always subjected to quick short-circuit through the digester center relative to the slow fermentation broth moving on both wings, leaving two dead zones as illustrated in Figure 8. Two direct consequences from this are the incomplete feedstock digestion and insufficient digester working volume utilization. In order to avoid such an uneven flow distribution in column digester, an arc baffle is specially designed in this invention to lead influent along the entire column circumference towards effluent port so as to avoid feed short-circuit and dead zone formations, which is expected to lengthen feedstock retention time 2~3 times and at least double the digester effective working volume.

As a consequence of the slow flow of floating scum in small-scale digester, crustation occur on the fermentation broth surface obstructing biogas release from liquid to gas phases. Manual smash has to be carried out in practice to prevent crustation during digester operation, giving nuisance and risk to operator. In order to automatically preclude such a liability for curst formation, the baffle in Figure 9 is particularly designed with a height in the middle of biogas chamber so that the possible crust would come across the baffle top along with the fermentation broth level fluctuation up and down caused by the biogas production and usage. In this way, enough dynamics are provided for effective crust shatter.

Besides fermentation broth auto-recirculation enabled repeated inoculation (Figure 7), fermentative biomas can also be retained through biofilm formation on inner digester surface. To realize such a biomass retention strategy, high specific surface inner wall structure can be fabricated to provide space for bacterial attachment and propagation. Rough surface and protruding structure could be very good choices, while special notice should be taken to avoid any possible clogging. Figure 10 demonstrates an example wall surface structure with more smooth surfaces exposing towards the flow direction. Bacterial film is expected to establish on these protruding surface facilitated by hydraulic shear force exerted from fermentative broth flow. It can be expected that the faster fermentative broth flows will give the thinner and denser bacterial film formation. Ultimately, a dynamic balance would be reached between biofilm growth and detachment. Those detached biomass would work as addtional inoculums for fresh feedstock fermentation.

Digested sludge effluent has been a nuisance in conventional anaerobic digester operation (Figure 1). Frequently, digested sludge piles up in fermentation chamber, blocking the new feedstock influent and occupying the effective working volume. If this happens, digester has to be put into idling state to empty all biogas before manually scooping is done though digester cap to dredge sludge congestion, which risks gives operator difficulties. In this case, an automatic desludge mechanics is necessary to be designed with small-scale digester to ensure a sustainable digester operation. In this invention disclosure, three measures are especially taken to facilitate an effective digested sludge flow towards outlet process, i.e. i) a greater than 5^o floor slope is designed to allow a gravity flow from inlet to outlet (Figure 7); ii) the fermentation broth auto-recirculation also help wash sludge sediment towards digester outlet (Figure 7); and moreover, iii) the arc baffle design in Figure 9 help lead digested sludge all the way towards digester outlet and thus avoid the any fermentation broth stagnation. These designs would allow all digested sludge to flow to the very end of digester effluent chamber from which they can be easily pumped out.

Farm always produces stalk materials that needs to be stabilized and also has potential for biogas production. While, stalk is not recommended to mix with animal manures in anaerobic digestion in this invention disclosure for three reasons, i.e. i) stalk has a rather poor biodegradability as compared to animal manure due to a layer of lignin skin encapsulating it. It always takes more than 90 days to give a complete degradation of stalk but animal manure only needs 30 days. Consequently, the mixture of stalk with manure will result in either enlarged digester volume or incomplete stalk biodegradation; ii) stalk generally owns a lower than animal manure density, thus they tend to float in the form of scum which is liable to cause crustation and block biogas dissociation in digester; iii) stalk are usually in relatively large particle size that is apt to clog digester and give difficulty to desludge. In this regard, a hydrolysis chamber is separately designed outside of digester in between the influent and effluent chambers and on the route of fermentation broth recirculation. Farm produced stalk wastes can be hydrolyzed here by hydrolytic bacterial continuously brought along with the fermentation broth recirculated (Figure 2). Ultimately, only hydrolysate from hydrolysis chamber flows into digester fermentation chamber, leaving the indigestible straw residual ready for disposal.

DESIGN GUIDELINE

V_d – digester total working volume (m^3)

V_g – biogas chamber volume (m^3)

V_c – column fermentation chamber volume (m^3)

V_b – slope spiral bottom volume (m^3)

V_f – water seal backfill volume (m^3)

V_i – influent chamber volume (m^3)

V_e – effluent chamber volume (m^3)

V_h – hydrolysis chamber volume (m^3)

h_f – frost depth (m)

h_g – biogas chamber height (m)

h_c – column fermentation chamber height (m)

h_b – slope spiral bottom height (m)

h_e – effluent chamber height (m)

Q_m - daily animal manure production ($m^3\ d^{-1}$)

t_m - manure retention time in digester (d), value between 30 ~ 40 d

R - feedstock biogas volumetric productivity, 0.2 to 0.4 $m^3\ m^{-3}$

n - daily biogas usage times

π - the ratio of the circumference of a circle to its diameter, around 3.1416

As illustrated in Figure 11, the disclosed small-scale digester design consists of a dome shape gas chamber (V_g), a column fermentation body (V_c) on a spiral slope bottom (V_b) as well as the influent (V_i), effluent (V_e) and hydrolysis (V_h) chambers.

The volume of fermentation broth can be determined by

$$V_d = Q_m \times t_m \quad (1)$$

Gas volume can be calculated by

$$V_g = 1/n\ V_b\ R \quad (2)$$

The diameter (D) of digester can be determined according to customer's ground layout. The height of doom cap can be determined with the gas chamber volume from the equation below,

$$V_g = \pi/6\ h_g\ (3\ D^2/4 + h_g) \quad (3)$$

Calculation for the net volume in digester cylinder main body,

$$V_c = V_d - V_g - V_b \quad (4)$$

Calculation for the height of digester cylinder main body,

$$h_c = 4V_c/\ \pi\ D^2 \quad (5)$$

Height of the spiral slope bottom, unit (m)

$$h_b = \pi\ D\ \tan(5^o) \quad (6)$$

Calculation for the volume of the spiral slope bottom, unit (m)

$$V_b = 1/8\ h_b\ \pi\ D^2 \quad (7)$$

Influent chamber comprises a rectangle tank in connection with an influent tube. In this fermentation broth auto-recirculation design, the feed chamber functions not only as a slot to feed feedstock but also a reservoir to store the biogas displaced fermentation broth that is to be recirculated back to inlet. Thus, it should be aware that the volume of this influent chamber directly determines the extent of the recirculated fermentation broth (Figure 11). In this regard, the influent chamber volume can be determined by,

$$V_i = V_g - V_e\ h_f\ /\ h_e \quad (8)$$

The influent tube could be 200 to 300 mm in diameter, and it should have a greater than 60^o slope and reach all the way to the digester inlet bottom. Moreover, a back valve should be installed at the end of this influent tube to prevent any fermentation broth backflow possibility.

The effluent chamber is responsible for three functions, i.e. desludge, manhole and transference of fermentation broth to hydrolysis chamber. Dimension for discharging chamber can be L×W = 1000×1000 mm, and its height measures from the top of the digester to bottom, which according to Figure 11 is close to,

$$h_e = h_f + h_g + h_c + h_b \quad (9)$$

Hydrolysis chamber hydrolyzes agriculture straw, and the volume of the hydrolysis chamber should be designed according to the farm daily straw wastes rate and the required hydrolysis duration. i.e.

$$V_h = Q_s \times t_h \quad (10)$$

in which,

Q_s – straw wastes production rate ($m^3\ d^{-1}$)

t_h – estimated hydrolysis time (d) which is around 90 days

A back valve should be installed on the bottom of the wall between effluent and hydrolysis chambers to ensure that liquid won't flow back from the hydrolysis chamber into effluent chambers.

An easy method to determine the baffle location is illustrated in Figure 12. Two same radius circles can be drawn by the centers of quadrant A and tangent B points. Then, a third same radius circle can be drawn by the center of the intersection C point. The arc segment between B and D thus can be used as a trail for baffle construction.

EXAMPLE

Assuming 18 dairy cattle are bred in a small farm which may produce $Q_m = 0.5\ m^3$ cattle manure daily (Klickitat County Solid Waste 2005), and manure retention time in digester is designed at $t_m = 30$ days, the volume of fermentation chamber can be derived according to Eq. (1), i.e.

$$V_d = 0.5\ m^3\ d^{-1} \times 30\ d = 15\ m^3 \qquad (11)$$

Digester diameter is chosen at D = 3.5 m in this design, and thereby the high of digester bottom can be calculated with Eq.(6),

$$h_b = \pi\ D\ \tan(5^o) = 3.14 \times 3.5 \times 0.09 = 1.00\ m \qquad (12)$$

Hence, digester bottom volume can be derived with Eq. (7), i.e.

$$V_b = 1/8\times\pi\times D^2\times\pi\times D\times\tan(5^o) = 1/8\times\pi\times 3.5^2\times\pi\times 3.5\times\tan(5^o) \qquad (13)$$

$$= 4.62\ m^3$$

Assuming a volumetric biogas production rate at $R = 0.4\ m^3\ m^{-3}$ and a biogas usage frequency at twice a day, the gas chamber can be determined with reference to Eq. (2) as,

$$V_g = 1/2 \times 15 \times 0.4 = 3\ m^3 \qquad (14)$$

Accordingly, the height of digester column main body can be calculated by,

$$h_c = (V_f - V_g - V_b) \times 4/(\pi\times D^2) = (15-3-4.62)\times 4/(3.14 \times 3.5^2) = 0.77\ m \qquad (15)$$

The height of spherical cap of biogas chamber can be solved from Eq. (3),

$$h_g = 0.6\ m \qquad (16)$$

The length and width for effluent chamber are designed at 0.7 m and the depth for effluent chamber measures from the top to the bottom of the digester and can be estimated by Eq. 11, i.e.

Take the frost depth in Pullman, WA which is 0.76 m for example, h_f in Figure 11 is thus chosen at 0.80 m in this disclosure, thereby

$h_e = h_f + h_g + h_c + h_b = 0.8 + 0.6 + 1.08 + 1.00 = 3.48$ m (17)

Therefore, the volume of effluent chamber can be calculated as,

$V_e = 1.00^2 \times 3.48 = 3.48$ m^3 (18)

The volume of influent chamber can be determined from Eq. (8), i.e.

$V_i = V_g – V_e h_i/h_e = 3 – 3.48 \times 0.8/3.48 = 2.20$ m^3 (19)

If W × H is chosen at 1.00 × 0.8 m, the L can be calculated as 2.75 m.

Suppose a 1.00 m^3 straw materials are produced per quarter in small farm, the dimension for hydrolysis chamber would have a volume of 1.00 m^3 according to Eq. (10), the dimension of the straw storage space part in hydrolysis chamber can be designed in W×L×H = 0.7 × 0.8 × 1.75 m.

Safety and construction

1. A security valve should be installed on the top of biogas chamber to release the extra pressure that may exceed the structural strength.
2. The earth thickness above digester cover should be no less than the local frost depth, e.g. 250 mm in Pullman, WA.
3. The digester structural strength should have a safety factor K≧2.65
4. The digester should be totally airtight. The maximum biogas pressure in digester should be lower than 8000 Pa, and 24 hours leakage should be less than 3%.
5. The initial feedstock amount should be between 50~90% of digester working volume.

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