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DESIGN OF DOMESTIC SCALE BIO-DIGESTER ASSEMBLY, EXPERIMENTATION FOR BIOGAS PRODUCTION AND COMPARISON OF RESULTS WITH CONVENTIONAL DIGESTER

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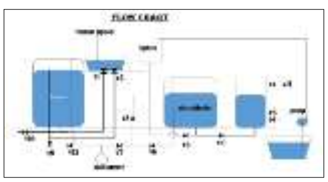
Graphical abstract



Abstract

The work explored various digesters that are currently under implementation, explored their pros and cons and designed a digestion gas collection mechanism suitable for small scale applications. Internal mixing being uneconomical in the domestic and individual scale, it is not being practiced which has to be compensated with large hydraulic retention time to prevent sludge accumulation and scum formation. This in turn reduces the plant capacity for gas production. Our design configuration incorporates automatic and controlled pressure swing mechanisms incorporated by the gas production which acts as the driving force for slurry circulation in the digester and promotes gas recovery as well as improve digestion efficiency. The configuration was run in 20 l and 50 L scales and observed for the physical constraints encountered during operation, recorded for change in digestion parameters with changes in substrate and organic loading rates and also recorded the gas production which was compared with the results in the literature as well as conventionally operated domestic scale digesters.

Keywords: Hydraulicretention time, digestion, organic loading rates, temperature

Abstrak

Kerja-kerja ini diterokai pelbagai pencerna yang sedang dalam pelaksanaan, diterokai kebaikan dan keburukan mereka dan mereka bentuk satu penghadaman mekanisme pengumpulan gas yang sesuai untuk aplikasi kecil. Pencampuran dalaman yang tidak ekonomi dalam skala tempatan dan individu, ia tidak diamalkan yang perlu diberi pampasan dengan besar masa tahanan hidraulik untuk mencegah pengumpulan enapcemar dan pembentukan buih. Ini seterusnya mengurangkan kapasiti kilang untuk pengeluaran gas. Konfigurasi reka bentuk kami menggabungkan mekanisme ayunan tekanan automatik dan dikawal diperbadankan oleh pengeluaran gas yang bertindak sebagai kuasa memandu untuk edaran buburan dalam pencerna dan menggalakkan pemulihan gas serta meningkatkan kecekapan penghadaman. Konfigurasi telah dijalankan di 20 l dan 50 L skala dan diperhatikan untuk kekangan fizikal yang dihadapi semasa operasi, mencatatkan perubahan dalam parameter penghadaman dengan perubahan dalam substrat dan kadar muatan organik dan juga mencatatkan pengeluaran gas yang telah dibandingkan dengan keputusan dalam kesusasteraan dan juga konvensional beroperasi pencerna skala domestik.

Kata kunci: Masa Hydraulicretention , penghadaman , kadar muatan organik , suhu

1.0 INTRODUCTION

Waste disposal in assorted form and depletion of conventional fossil fuels have collectively become the major problem in India which could not be solved despite many initiatives by the government. These problems can together be addressed by installation of the biogas plants per family in the localities of both rural and urbanized societies. Biofuels have been considered to be clean fuels and recognized as the significant alternative for replacing the continually depleting conventional fossil fuels. Gasification or liquefying of biomass that is unsuitable for combustion and there by deriving chemicals as well as fuels with good calorific value by applying methods of physical decomposition or biodegradation has found to be practiced in recent trends and is a topic of vital importance in current research. Out of the conventional methods used for gasification, biodegradation has been found to be advantageous over physical methods.

The biogas plant setup that is most feasible and compact for the domestic applications was designed in this paper.For this we have gone through the various digester designs that are under implementation and designed the self circulatory digester setup and run on the various scales and fixed the operating parameters in the digester. The digester setup was tested for gas production and the results were compared with the conventional digesters and the variation parameters was tallied and validated with the data existing in the literature.

2.0 EXISTING DESIGNS

Following table depicts various varieties of biogas plant units that are currently operational with a brief description on their pros and cons along with the suitability of operation.

Table 1 depicts various varieties of biogas plant units that are currently operational with a brief description on their pros and cons along with the suitability of operation.

3.0 INITIAL DESIGN

The digester is an inverted vessel containing the provision for an inlet of 'U' shaped 4 inch ID pipe as shown in the Figure 1 which has longer arm outside the digester while the shorter end is projected inside towards the top end. Another 4 inch pipe takes a U turn from the tank bottom is provided for acting as outlet to the digester. Pipe of size (1 or ¾ or ½ inch) depending on the rigidity required which in turn depends on the length of pipe required inside the digester. This pipe is used for transferring the accumulated gas on the surface of the liquid in the digester to the separate gas collector. Pipe is introduced from the bottom to solve the purpose of

1. Reducing the efforts of making the dome top as gas proof instead the bottom is made liquid sealed which is much simpler.
2. Leaving the dome top reduces the wear and tear of the digester wall due to the fluctuations achieved in the pressure of the gas inside the container.

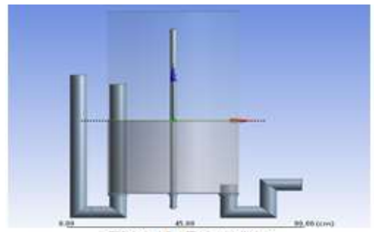


Figure1: Front view

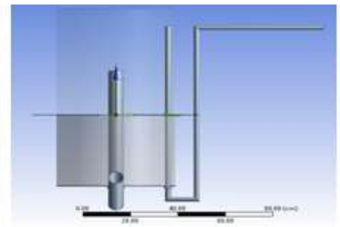


Figure 2: Side view

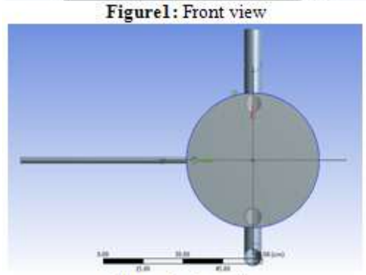


Figure 3: Top view

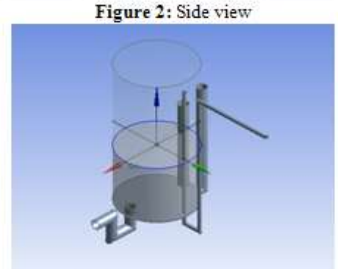


Figure 4: Isometric view

4.0 METHODOLOGY AND EXPERIMENTS

The digester gas collector setup was first tested in 20L scale which lead to the modifications in the design and it was later implemented in 50 L scale that lead to our final design.

4.1 Setup-1 20l

The setup was intentionally made to be transparent to clearly observe the phenomena of scum formation and the zones of settlement. Due to the availability of light, methane production was very slow initially which took 10 days for the gas collected to attain flammability.

1. The reactor design is initially tested for the feasibility using a 20 liters transparent digester (Fig 8) with a pipe sealed everywhere except at one bottom joint so that when the 1 ½ inch diameters PVC pipe is removed at that particular joint, it will act as sludge outlet and when it is closed back, it can act as slurry inlet.

Table 1 Conventional Digester designs

No	Type	Description	Review	Existing models
1	Fixed dome digester	Installed underground with feed inlet and outlet on the ground level. Dome is projected above ground which has gas outlet valve. Life span: 20 years minimum with regular and periodical maintenance. Capacity: versatile 5 to 200 cubic meters[1].	Advantages: Simplest, no moving parts Underground, protected, no temperature fluctuations, Laborious and meant to create employment if any society beneficial or rural development program has been undertaken [1] Disadvantages: Tedious in construction and perfect coating for gas proof coating is required. Substantial fluctuation in gas pressure.	Initiative by China and introduced in India as Janta model which was re launched with certain leak proof modifications as Deenbandhu model and presently recommended as simplified hemi spherical dome shaped CAMARTEC model.
2	Floating dome digester	Moving gas holder is an inverted drum suspended in the upright digester containing slurry which acts as liquid seal. Drum movement depicts the production and consumption of gas. Medium scale production is recommended for the capacity of 5-15 cubic m digester and large operation at 50 -200 cubic meters [1].	Advantages: Easy to understand and operate Gas production is always detectable Disadvantages: Higher installation costs Harder in maintenance Clogging is encountered due to scum formation reducing the free movement of gas holder inside the digester which requires frequent monitored cleaning in case of operation with fibrous feed stocks.	KVIC model A cylindrical digester, the oldest floating drum model Pragati model: A hemisphere digester. Ganesh model: It is made up of angular steel and plastic foil BORDA model: Combines the static advantages of hemispherical digester along with the process-stability of the floating-drum and longer life span of water - jacket plant.
3	Balloon plants	Heat sealed plastic flexible variable volume container as the gas collector Gas pressure is manipulated by placing weight on balloon. Material has to be weather, UV resistance.	Advantages: Low initial investment Easy installation Disadvantages: Short useful life span (2 to 5 years) Scum removal is difficult. Identification of leaks is tedious. Continuous human intervention for acting on the repairs is required.	Installed with same name.

2. Gas outlet pipe is made out through the sealed bottom and introduced into the transparent container of 10 liters capacity which is inverted into the bucket of 15 liters capacity already filled with water.
3. Weights are introduced on the inverted gas collector to maintain the rigidity of the assembly.
4. Cow dung was made into slurry by mixing with water in the 1:1 (v/v) proportion. Slurry of 16 liters was fed to the digester and observed for batch production.
5. The slurry was retained for 10 days and was observed for its operational feasibility and noting the technical difficulties to be encountered.
6. Everyday gas production was observed by the overflow of water from the bucket as well as the rise of slurry level inside the feed pipe.

Figure 5 Digester setup

Figure 6 Gas collector

Figure 7 Overall setup

Observations:

1. Gas production was observed from the second day of loading and was rapid during the day time and low during the nights.

2. Amount of water overflow from the digester used to get increased with days during initial period of HRT and finally started to get reduced with time.

3. Constituents were made undergone intermittent aeration after 4 days of HRT and the gas production was notably good compared to that observed in the previous day.

Flame characteristics:

- Initially aberrations were observed followed by instant put off from 5th day stating considerable carbon dioxide fraction.

- Bluishness followed by instant termination was seen from 6th day to 8th day which signifies raised methane concentrations. On 9th day, rise with bluishness followed by stabilization and termination on increasing flow rate of gas was observed.

Practical difficulties and operational constraints:

1. Clogging was the most significant difficulty observed in the design which was resulted due to the sedimentation and the pipe diameter was not sufficient to for the free passage of thickened sludge. This urged for increasing the inlet and outlet pipe diameters for the next constructed design.

2. Gas deposition at the top of the slurry surface was not much satisfactory because of the entrapment of the gas in the form of the packets of significant size. This entrapment used to reduce the density of dung due to which three zones of;

   a. Thickened zone: bottom thick sludge.

   b. Clarified zone: water with dissolved solids

   c. Top zone: some dung used to rise above the water because it used to contain entrapped biogas in it due to which the overall density of the dung-gas mixture was found to be reduced to below that of water with dissolved solids.

Solutions:

1. Proper mixing is the first recommended solution to the above problems related to clogging.
2. Reducing the density of the feed inlet and the formation of the third layer is expected to be less frequently encountered in case of other ground feed stocks used to be used in this experiments.

3. Also increase in the cross section of the digester is the significant solution to the problems related to the gas entrapment.

These changes have been incorporated with much more sophistication in the assembly using 50 liters digester. Initially transparent vessel of 20 liters capacity was used as gas collector but due to its gradual failure to remain water sealed lead us to fabricate 50 liters sealed container to use as gas collector.

4.2 Setup-2 50 L

Digester design as presented earlier was constructed with the same specifications mentioned with a capacity of 50 liters as the effective working volume and run on test for 45 days. During this period, cow dung was initially fed to the digester and retained for 2 weeks, monitoring the parameters for developing the self-buffering ecology suitable for methane production. Simultaneously, batch test on gas production has been conducted. Digester was then fed with tomato wastes in semi continuous mode and run for 30 days monitoring the process parameters and gas production.

The set up was successfully constructed and observed for the operational convenience and associated practical difficulties.

Advantages:

1. Due to the enhanced cross sectional area, the bubble entrapment has been reduced.
2. The construction has been supporting the vertical mixing without wear and tear as well as the elimination of interruption in the gas holding space.
3. No choking problems have been encountered in the 45 days retention without much vertical mixing, although the sediment sludge at the end of digestion has the solid content of nearly 15 % by mass.
4. Perfect gas seal and reactor-collector communication have been observed and the assembly showed convenience for efficient mixing.

Disadvantages:

1. Manual mixing was difficult than expected.
2. Fungal growth has been observed in the open spaces

Figure 8 50 LExperimental setup

4.3 Feed Stock Properties

Table 2 Properties of feed stocks used in the analysis

	Substrate		Cow dung	Tomato waste
S no	Parameter	Unit	Value	Value
1	Moisture content	% w/w	86.48	73.665
2	Total solids	% w/w	13.52	26.33
3	Volatile solids	% w/w of total solids	81.71	94.68
4	pH		7.1	4.6
5	Temperature	^0C	30	30

4.4 Parameters For Operation

Shown below are the suggested set of parameters for steady and optimum operation for methane rich gas production and safe digestion operation.

Temperature: 30 to 40 0C

pH: 6.8 to 7.5

Table 3 Parameters for optimization

HRT	OLR (Kg VS/m^3 day)	VS fraction (w/w)
20	2	0.04
25	1.6	0.04
30	2	0.06
30	1.333	0.04
20	3.5	0.07

5.0 OBSERVATIONS

5.1 Batch Experiment

Cow dung was mixed with water in the ratio of 4:5 V/V which was fed to the digester and retained for the development of culture during which the batch observations were recorded.

Table 4 Batch experiment results

Day	pH	Temp. ^0C	Volume (L)	Cumulative Volume (L)
0	7.1	28	0	0
1	6.9	29.3	0	0
2	6.8	30.7	0	0
3	6.7	31.2	2.2	2.2
4	6.5	31.4	2.5	4.7
5	6.8	32.1	3.3	8.0
6	6.9	31.9	3.5	11.5
7	6.9	32.6	3.9	15.4
8	7.0	32.3	4.2	19.6
9	7.1	33.1	3.6	23.2
10	7.0	32.7	3.3	27.5

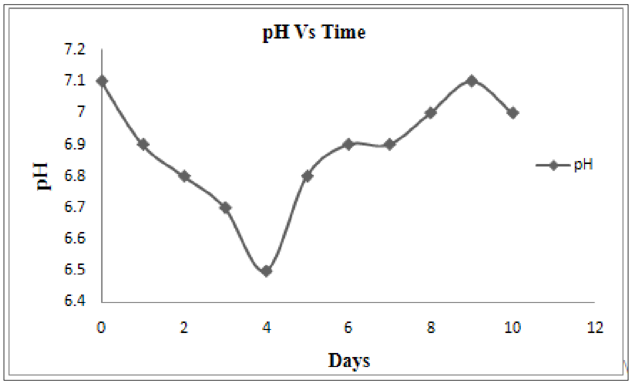


Figure 9 pH Vs Time

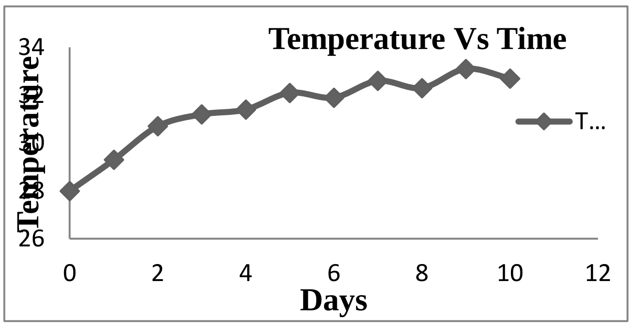


Figure 10 Temperature Vs Time

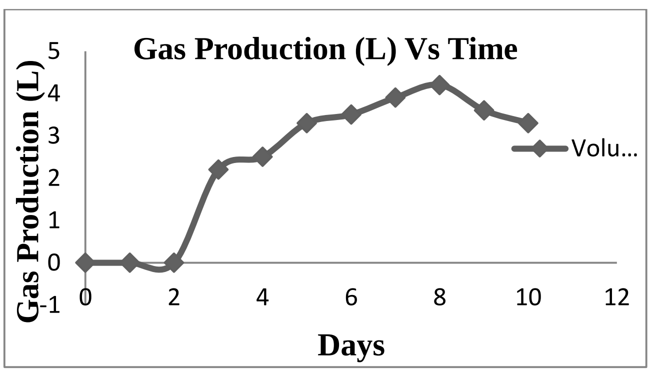


Figure 11 Gas production Vs Time

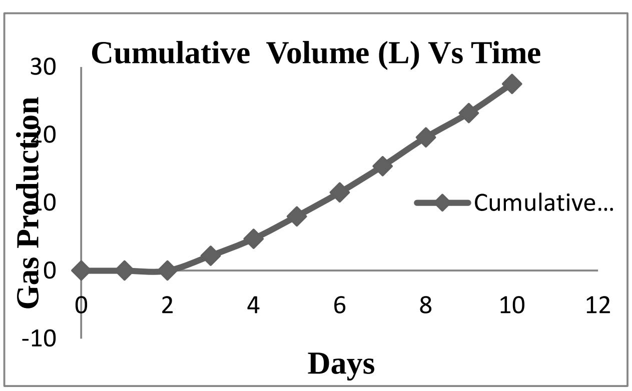


Figure 12 Cumulative Gas production Vs Time

5.2 Semi Continuous Experiment

Table 5 Parameters used in the experiment

Duration	HRT	OLR (Kg VS/m³ day)	VS fraction (w/w)
1st Week	25	1.6	0.04
2nd Week	20	3.5	0.07
3rd Week	16	5	0.08

Table 6 Observations for semi continuous experiment

Day	pH	Temp. °C	Volume (L)	Cumulative Volume (L)
0	6.9	30	3.4	3.4
1	6.9	31.7	3.8	7.2
2	6.7	32.3	4.9	12.1
3	6.5	32.9	2.3	14.4
4	6.8	31.5	3	17.4
5	7	32.8	12.9	30.3
6	7.2	33.2	18.6	48.9
7	7.1	32.8	23.9	72.8
8	7.1	34.1	22.5	95.3
9	6.9	32.8	19.3	114.6
10	7	32.2	18.5	133.1
11	7.1	33.6	17.6	150.7
12	6.8	33.9	11.6	162.3
13	6.5	31.9	7.3	169.6
14	6.4	32.6	5.8	175.4
15	6.2	33.2	2.8	178.2
16	6	33.2	0	178.2
17	5.7	33.6	0	178.2
18	5.8	33.3	0	178.2
19	5.6	32.1	0	178.2
20	5.5	30.8	0	178.2

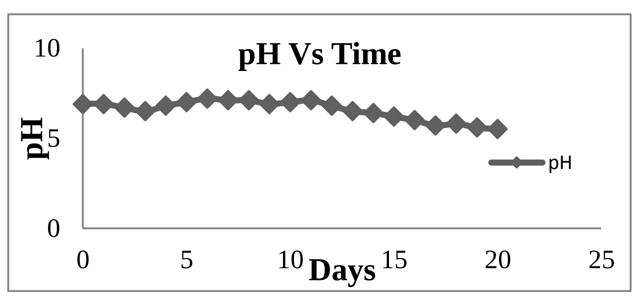


Figure 13 pH Vs Time

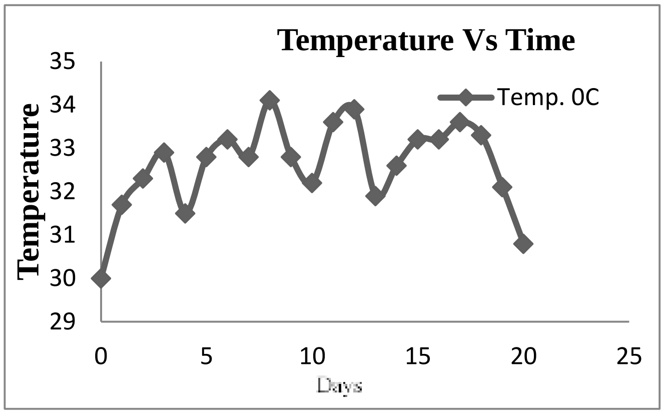


Figure 14 Temperature Vs Time

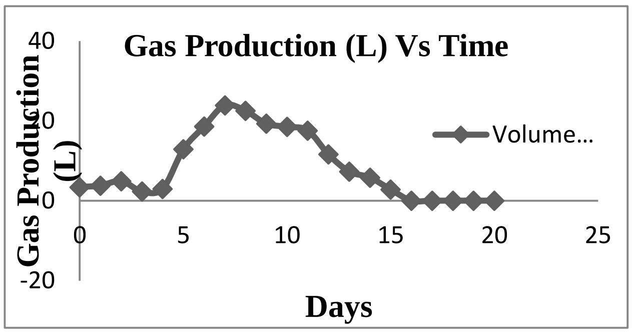


Figure 15 Gas production Vs Time

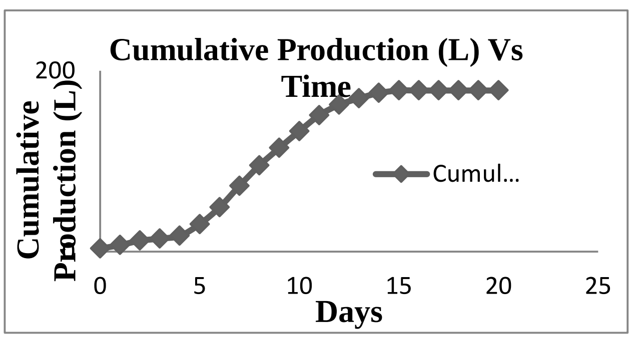


Figure 16 Cumulative Gas production Vs Time

During the semi continuous study, the tomato wastes used were acidic in nature with pH 4.3 which resulted in higher Volatile Fatty Acid accumulation and pH fell drastically to 5.7 on 17th day of semi continuous operation i.e. 20th day of installation. Gas production was entirely terminated and yet the digester was active which could be observed by the consistent above 30 0C temperatures of digester even though the temperature of ambience reached 23- 25 0C. Berlian setarous et. al.[9] has conducted experiments on 200 liters batch digester which has gone sore (pH below 6) after 3rd week of installation and it got stabilized to neutral and attained self-buffering capacity after the 9th week of installation. The digester was retained for two more weeks and was dismantled after retaining for two more weeks.

Considering the modifications that are required in the construction and operation which would ease the maintenance of the digester, we are forwarding for 200 L scale anaerobic co-digestion.

6.0 FINAL DESIGN

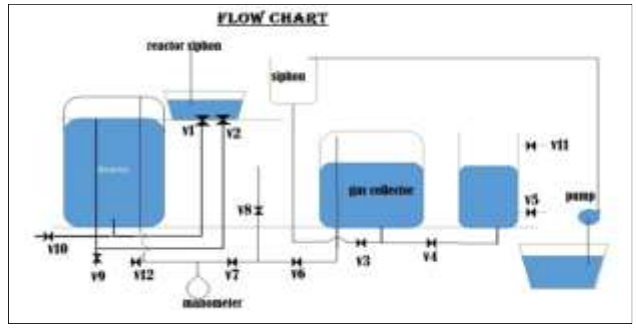


Figure 17 Digester gas collector configuration 2D view

Working:

Step 0:

Reactor is to be filled with the diluted substrate and the gas collector assembly is to be filled with water to the designed container levels and all valves are now closed after ensuring that pressure is 1 atm in the gas space of reactor as well as gas collector. Assembly is left undisturbed until the pressure in the reactor gas space reaches P1 atm.

Step 1:

V1 is now opened keeping all other valves closed. This would result in the accumulation of slurry from the bottom of the digester in the reactor siphon. New equilibrium pressure is developed in the digester gas space which is to be denoted by P2.

Step 2:

V1 is to be closed and simultaneously opening V2, V4, V6, V7 and V11. This would now push some of the substrate that was previously accumulated in the reactor siphon into the digester through its inlet which would reach top slurry level. After the equilibrium is reached, at the pressure P3 which will be less than P2 but greater than atmospheric pressure.

Step 3:

Now V2 and V4 are closed. Keeping V6 and V7 open, V1 and V3 are simultaneously open turning the pump on. Adding water through the siphon to the gas collector would rise the pressure in the collector followed by the reactor which results in the pushing of slurry from the outlet pipe into the reactor siphon through valve V2.

Step 4:

After attaining the sufficient level of slurry accumulation in the reactor siphon, V3 and V2 are closed simultaneously opening V1, V4 and V11which would repeat the cycle again pushing back slurry in the reactor siphon to the surface.

Pump used for water pumping has the circuit connected to the level indicator in the siphon. Thus when the level in the siphon reaches maximum value, pump gets switched off. A slight reduction in the water level of the siphon switches the pump on. When V3 is closed in step 4, water is filled to the maximum level in the siphon and pump turns off. While repeating the cycle again, from step 2, to push the gas in the reactor, net hydraulic head provided by siphon –that of reactor siphon acts as driving force, and when the level of water in the siphon descends, pump automatically turns on.

Pressure relations:

Following equation relates the net volume of slurry that is recycled in first cycleafter gas production and to the pressure attained in the reactor gas spaceP1:

$$2(V_2^R - V_0^R) = [\{V_0^R - (A^{RS}\beta P_o)/((\beta+1)*\rho_s g)\}^2 + 4*(A^{RS}\beta P_1 Z_2 T_2 V_0^R)/((\beta+1)*\rho_s g\ Z_1 T_1)]^{1/2} -- (A^{RS}\beta P_o)/((\beta+1)*\rho_s g) - V_0^R$$

Where $\beta = (A^R - A^p)/ A^{RS}$

This gives height attained by slurry level in the reactor siphon $H^{RS} = (V_2R - V_0R)/A^{RS}$.

Terminology:

V2R = volume of the gas space in the reactor after step 1.
V_0^R = initial volume of the gas space in the reactor.
A^R = cross section area of the reactor.
A^P = cross section area of the slurry inlet pipe.
A^{RS}= cross section area of the reactor siphon.
P_o = atmospheric pressure.
ρ_s = slurry density.
g = acceleration due to gravity.
P_1 = pressure attained in the reactor gas space after step 1.

Z_1 and Z_2 are the compressibility factors corresponding to temperatures T1 and T2 during step 1 and step 2 respectively.

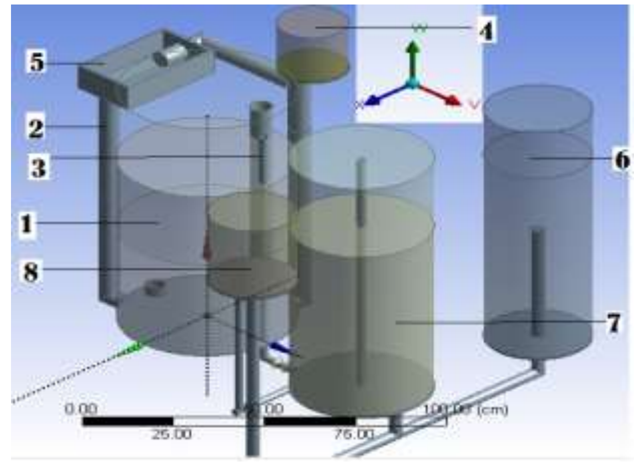


Figure 18 Digester gas collector configuration 3D view

Labeling:

1. Reactor, 2. Outlet 3. Gas pipe 4. Inlet 5. aSlurry mixer cum reactor siphon 6. Pressure equilibrating water column, 7. Gas collector and 8. Gas collector siphon.

7.0 CONCLUSION

Design presented in this paper is:

- Expected to have more efficiency of gas production which is enhanced due to continual mixing.
- Lower failure probability as the total gas collector boundary is immobile and indirect boundary in the form of water level always moves.
- Higher is the scale of operation, faster is the attainment of mixing cycle.
- Complete manual control and very ease of maintenance and replacement as no part is directly connected directly to the constituents that react thus replacing any component does not interact the process.
- Driving force for missing is supplied from water pump which is much cheaper compared to slurry pump and lot easier to maintain.

ARTI biogas digester design uses HRT of 42 days to compensate for the lack of internal mixing where as the digester presented in this paper is observed to be stable at 24 Days HRT and thus gives more gas production. For the scales above 2 cubic meters of digester capacity, the water displacement gas collector can be replaced by balloon type collector with intermediate gas pressure regulating valve to give the same pressure swing and mixing effect. We are now working on the design of automatic control loop for the cycle explained in the design and also conducting experiments in 200 L scale.

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