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Analysis of Psychrophilic Alternatives for Production of Biogas at Colder Temperature Range

Ritavrat Joshi*, Dr. Ajay Kumar Jha

Department of Mechanical Engineering, IOE, Pulchowk Campus, TU –Nepal

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***Corresponding author:** Ritavrat Joshi

Abstract **Original Research Article**

Biogas is a proven and widely used renewable energy technology which has been contributing to the environmental as well as social benefits. However, the limitation to the technology is that it has only been effective in mesophilic temperature range. This research has focused on study of biogas production potential in psychrophilic temperature range. Psychrophilic methanogens are found in permafrost sediments/ lake bottom of high-altitude lakes where the temperature is low. With overall research support from Cascade Research and Engineering Services (CaRES) Pvt. Ltd., who had samples collected from high altitude lakes of Gangapurna, and Gokyo, bench level digesters were prepared for this research purpose with various amount of organic feed. The digester was also tested adding only the organic wastes for comparative study. Three digesters were kept at room temperature (mesophilic temperature range). The so formed digesters were kept at 5 and 10 degree Celsius. The pressure reading and temperature of the samples were noted. After period of 55 days, the gas pressure and the gas composition were tested. The results showed increased biogas production while using the sample compared to the digester without the sample at same temperature. However, the biogas formed at the low temperature was still low compared to the biogas produced at mesophilic temperature range (room temperature). With the help of the biogas production potential as calculated, cylindrical biogas digester was designed of 2 m3 volume. The calculations showed 30 kg of organic wastes required per day for the designed biogas digester.

Keywords: Biogas, high altitude digesters, psychrophilic methanogens.

INTRODUCTION

Biogas has been efficiently produced using mesophilic bacteria, which grow best in moderate temperatures (20-35°C) [1]. But these bacteria exhibit significantly reduced biogas production potential for high altitude regions where temperatures fall as lows as 15 degree [2]. To solve this problem, focus has shifted to another group of bacteria termed as psychrophiles, which grow best at temperatures between -20°C to 15°C. Evidences of existence of probable methanogenicpsychrophiles have been found in permafrost sediments of frozen lakes (in Alaska and Nepal) [3]. These bacteria are capable of production of biogas even at temperatures as low as 0º C. However, research- based data is not available about methane producing capability of psychrophiles isolated from permafrost sediments in Nepal using conventional feed readily available in rural households (human, animal and kitchen wastes).

This research focuses on analyzing the methane production of the psychrophiles isolated from permafrost sediments of lakes in Nepal. During the course of research, the focus of the research was shifted to analyzing the methane production potential of the psychrophiles present in the permafrost samples collected from various parts of Nepal. The samples were first analyzed in laboratory for the identification of the presence of psychrophilic methanogens. Then the samples were used in prototype biogas digesters in the laboratory which were kept at different temperatures and at varying feed compositions. The gas produced in the digesters was studied for its composition. The data regarding the gas production potential were analyzed and were used to formulate a bio-gas digester design of 2 m3 volume. The so formulated bio-gas digester design will be beneficial for increasing the biogas production in psychrophilic temperature range.

OBJECTIVES

The specific objectives of this study were:

- To compare methane producing capability of psychrophilic and mesophilic methanogens.
- To establish experimental pilot setup for production of biogas using psychrophilic and mesophilic methanogens using organic household waste as substrate.
- To identify and formulate design parameters for construction of biogas digester feasible in cold climate of high altitude using psychrophilic methanogens.

METHODOLOGY

This research followed a confirmatory approach and a case study design. The primary data source for the verification of psychrophilic bacteria was confirmatory lab tests whereas secondary data was attained through research papers and articles as well as other relevant ongoing projects. Permafrost was decided to be the best sample type for this purpose and keeping this in mind, organic soil was taken from such areas (1-2m deep). This constituted of slimy and sludgy soil as well.

Further methods implemented during this research project are as follows:

Identification of possible sampling sites and sample collection

Literature review was carried out with researchers from Cascade Research and Engineering Services (CaRES) Pvt. Ltd. to identify sampling sites based on average temperature and wetland availability. The samples were collected so as to be used in isolation and characterization of psychrophiles. Samples were collected from a depth of about 1-2 meters below the water level. Samples were stored in falcon tubes, sealed with parafilm and stored in ice boxes maintained. Temperature inside the box was maintained at below 10°C during transportation.

Table-1: Details of sample collection from Manang

S.No	Location	Number of Samples	Nature of Samples	Altitude	Soil temperature
1.	Natural pond, TeManang	1	Lake sediment	3572 m	-1.3°C
2.	Gangapurna lake, Manang	3	Lake sediment	3570m	0.9°C
3.	Natural pond, Pisang	1	Lake sediment	3314m	1°C
4.	Natural pond, Pisang	1	Lake sediment	3348m	1.5°C
5.	Gosainkunda, Rasuwa	2	Lake Sediment	4380	-1.5
6.	Natural Pond, Lauribinayak, Rasuwa	1	Wetland Sediment	3846	0.2
7.	Gokyo Lake, Solukhumbu	2	Lake Sediment	4788	-2.1
8.	Syangboche, Solukhumbu	1	Fecal waste	3846	1.7

In the second stage of sample collection, samples were collected from two different sites of Solukhumbu district so as to be used in prototype biogas digesters. These sites were selected based on the amount of organic matter available. One sample was collected from a relatively barren part of the lake with no visible access to organic matter while the other site had some vegetation. Samples were collected from a depth of about 1-2 meters below the water level.

Determination of amount and composition of available household waste:

A survey was carried out in about 30 households of Manang and Tanki VDC. Face to face interviews were conducted and the questions were asked based on the prepared questionnaire.

Isolation and characterization of bacteria:

For ease during isolation, the soil samples collected from Gangapurna lake were named with their respective abbreviations as follows:

- TeManang Sample: T
- Gangapurna Sample: G1, G2, G3 (collected from different parts of the same lake) Pisang samples: P1, P2
- Gosaikunda sample: GO1, GO2 Lauribinayak sample: L
- Gokyo Lake sample: S1 (greener part), S2 (barren part)
- Syangboche sample: S3

With help from biotechnologists from CaRES

- The soil samples were serially diluted to concentrations ranging from 10^{-1} to 10^{-5}.

- MSH media was used for the isolation of desired bacteria. Stock solutions were prepared and kept for use.
- Master plates were prepared from the soil samples using the spread plate technique. In total, 22 plates were inoculated.
- Subculture of the isolated colonies was done using the quadrant streaking method.
- Incubation: After inoculation, plates were placed inside an airtight chamber (box), a candle was lit and the lid was closed. The candle extinguished after about 2 minutes and the chamber was then supposed to have become airtight. The box was placed in a refrigerator at 0 to 5 degrees Celsius.
- Along with morphological study, four tests were carried out for identification of bacteria including Gram's staining, catalase test, oxidase test, citrate utilization test and fluorescence test.

Preparation of reduced scale fermenters:

In total, 14 digesters were preparedfrom jars with different samples and were operated at three different temperatures: 10°C, 15°C and room temperature (20-25°C) with retention period of 60 days for each. Gokyo Lake samples were used for two different sets of digesters operated at temperatures 10, 15 and 25°C. Digesters with different feedstock composition were set up.

Table-2: Prototype digesters with mesophilic conditions

Composition Jar	Kitchen waste(kg)	Cow dung (kg)	Sample (kg)	Water (kg)	Temperature
Jar 0	1.5	1.5	-	2	15°C
Jar 1	1.5	1.5	-	2	Room Temp.
Jar 2	1.5	1.5	-	2	10°C
Jar 3	1.5	1.5	-	2	25°C
Jar 4	1.5	1.5	-	2	5°C

Table-3: Prototype digesters with S1* and S2 inoculums**

Composition Jar	Kitchen waste(kg)	Cow dung (kg)	Sample (kg)	Water (kg)	Temperature (T1 for 60 days)	Temperature (T2 for 60 days)	Temperature (T3 for 60 days)
Jar 5	1.5	1.5	1(S1)	2	25°C	15°C	10°C
Jar 6	2	-	1(S1)	2	25°C	15°C	10°C
Jar 7	2	-	1(S1)	2	25°C	15°C	10°C
Jar 8	1.5	1.5	1(S2)	2	25°C	15°C	10°C
Jar 9	2	-	1(S2)	2	25°C	15°C	10°C
Jar 10	1.5	1.5	1(S2)	2	25°C	15°C	10°C

Table-4: Prototype digesters with S3* inoculums**

Composition Jar	Kitchen waste(kg)	Cow dung(kg)	Sample (kg)	Water (kg)	Temperature (T1 for 60 days)	Temperature (T2 for 60 days)	Temperature (T3 for 60 days)
Jar 11	1.5	1.5	1(S3)	2	25°C	15°C	10°C
Jar 12	2		1(S3)	2	25°C	15°C	10°C
Jar 13	1.5	1.5	1(S3)	2	25°C	15°C	10°C

Note: S1, S2 and S3 are the samples from greener part of Gokyo, barren part and the samples from Syangboche respectively.

Pressure measurement:

Pressure readings were taken for the gas collected in the digesters using the following instruments:

- Digital Multimeter: Fluke DMM 117
- Digital Pressure Module: Fluke-Module PV 350

Determination of Composition:

The composition of the collected gas was determined using a digital gas analyzer: German gas analyzer Gas board – 3200P, which detected gases Methane (CH_4), Carbon dioxide (CO_2) and Hydrogen sulphide (H_2S). A burning flame from the gas outlet when exposed to a flame indicated positive result.

Conduction of Flame test:

Flame test was conducted for all the digesters. A burning flame from the gas outlet when exposed to a flame, indicated positive result.

Finally, all the required research paper and publications will be carried out as directed by IOE, Pulchowk.

RESULTS AND DISCUSSION

The average high temperature was 21°C in Manang and 17°C in Solukhumbu and the average low temperature was 0°C-1°C. The temperature of the soil at sample collection sites ranged from -2°C to 3°C.

Colony Morphology of Samples

After about 15 days of incubation, colonies started to appear on most of the master plates, except some. A common observation among all the colonies was that almost all of them were brightly colored, circular in shape and exhibited liquid-like colonies rather than solid ones. Distinct colonies from all the above master plates were sub-cultured and growth was observed in all of the plates. Again, the sub-cultured plates displayed continuous liquid-like morphology. Out of the obtained plates, 10 plates were selected for further biochemical tests and were named using numbers after the first letter M (eg. M1, M2, M3, M4 etc).

Table-5: Colony morphology of samples

Samples	Colony Morphology	Samples	Colony Morphology
G3 (10^{-3}) a	Pinkish Red (dense, watery)	G2(10^{-4})	No growth observed
G3 (10^{-4}) a	No growth observed	G4(10^{-3})	Yellow + White (both thin, watery)
G3 (10^{-4}) b	No growth observed	G4(10^{-4})	Orange (thin watery)
G3 (10^{-5}) a	No growth observed	P(10^{-3})	Yellowish orange (dense, watery)
G3 (10^{-5}) b	Yellow (dense, watery)	P(10^{-4})	Yellowish orange (dense, watery)
T (10^{-3}) a	No growth observed	DP (10^{-3})	No growth observed
T (10^{-3}) b	White + Yellow + Orange (all thin, watery)	DP (10^{-4})	No growth observed
T (10^{-4}) a	Yellow (thin, watery)	S1(10^{-3})	Slimy creamy + orange
T (10^{-4}) b	No growth observed	S1(10^{-4})	Slimy creamy + orange
T (10^{-5}) a	Slimy creamy+Orange(dense, watery)	S2(10^{-3})	Slimy creamy + orange
T (10^{-5}) b	No growth observed	S2(10^{-4})	Yellowish orange (dense, watery)
G1 (10^{-3})	No growth observed	S3(10^{-3})	Slimy creamy + orange
G1(10^{-4})	No growth observed	S3(10^{-4})	Slimy creamy + orange
G2(10^{-3})	No growth observed		

Characterization of Bacterial Samples

Four biochemical tests were performed followed by a fluorescence test for characterization of the bacterial samples obtained. The results for these tests are shown in Table below

Table-6: Biochemical test results

Colonies	Colony Name	Gram Staining Test	Catalase Test	Oxidase Test	Citrate Utilisation Test
G3(10-3)a (pinkish red)	M1	+ve (spherical)	+ve	+ve	-ve
T(10-5) a (orange)	M2	-ve (spherical)	+ve	-ve	-ve
T (10-4)a (yellow)	M3	+ve (spherical)	+ve	-ve	+ve
T (10-3)b (whitish yellow)	M4	+ve (rods)	+ve	-ve	+ve

T(10-3)b (orange)	M5	+ve (spherical)	+ve	-ve	-ve
G3 (10-5)b (yellow)	M6	+ve (spherical)	+ve	-ve	+ve
P(10-4) (yellowish orange)	M7	+ve (spherical)	+ve	+ve	-ve
G4(10-4) (orange)	M8	+ve (spherical)	+ve	+ve	-ve
G4 (10-4) (yellow)	M9	+ve (spherical)	+ve	+ve	-ve
G4(10-3) (white)	M10	+ve (spherical)	-ve	-ve	+ve
S1(10^{-3}) (Slimy creamy + orange)	M11	-ve (rods)	-ve	+ve	+ve
S1(10^{-4}) (Slimy creamy + orange)	M12	-ve (rods)	-ve	+ve	+ve
S2(10^{-3}) (Slimy creamy + orange)	M13	-ve (rods)	-ve	+ve	+ve
S2(10^{-4}) (Yellowish orange)	M14	+ve (spherical)	-ve	+ve	-ve
S3(10^{-3}) (Slimy creamy + orange)	M15	-ve (rods)	-ve	+ve	+ve
S3(10^{-4}) (Slimy creamy + orange)	M16	-ve (rods)	-ve	+ve	+ve

Any colony exhibiting positive results to Catalase tests were discarded since it indicates that the bacteria is of aerobic in nature which is contradictory to the purpose of methanogenesis. Since M11, M12, M13, M15 and M16 demonstrated the closest morphology to that of Psychrophiles, it was decided that from then on, the thesis should be focused on the prototype digester research with samples from Solukhumbu.

Gas Analysis

The total volume of each digesters formed were 20 liters. The volume of the gas in the jar was the total volume after the volume of the feed was deducted. A total of 60 days retention time was given before checking the gas composition. Jars 0-4 were under mesophilic conditions whereas the remaining was inoculated with samples from Solukhumbu.

Table-7: Methane production from mesophiles

Jar	Temp (K)	Gauge Pressure (kPA)	Gas Composition (vol %)					Gas volume (Ltr)	Flame Test
			CH4	CO2	H2S (ppm)	N2	H2		
Jar 0	288	202	31	28.2	0.714	38.2	1	15.0	+ve
Jar 1	296	448	64	21	0.798	12.8	1	16.0	+ve
Jar 2	283	192	24	37.1	0.612	37.2	1	15.0	+ve
Jar 3	298	545	63	22	0.768	12.9	1	14.0	+ve
Jar 4	278	171	9	17	0.186	73.3	1	14.8	-ve

Table-8: Methane production (60 days at T1 25 deg. C)

Jar	Temp (K)	Gauge Pressure (kPA)	Gas Composition (vol %)					Gas volume (Ltr)	Flame Test
			CH4	CO2	H2S	N2	H2		
Jar 5	298	426	66	20.8	0.347	11.8	1	14.0	+ve
Jar 6	298	422	61	21	0.008	16.9	1	15.0	-ve
Jar 7	298	412	62	19	0.012	17.2	1	14.0	-ve
Jar 8	298	456	65	18	0.044	15.8	1	14.0	-ve
Jar 9	298	474	61	21	0.006	16.5	1	15.0	-ve
Jar 10	298	432	64	20.4	0.346	14.2	1	15.0	+ve
Jar 11	298	458	64	22.6	0.408	11.2	1	15.0	+ve
Jar 12	298	434	63	19.8	0.206	15.3	1	16.0	+ve
Jar 13	298	414	66	19.1	0.169	13.2	1	14.0	+ve

Table-9: Methane Production at 15C

Jar	Temp (K)	Gauge Pressure (kPA)	Gas Composition (vol %)					Gas volume (Ltr)	Flame Test
			CH4	CO2	H2S	N2	H2		
Jar 5	288	392	58	21	0.242	19.2	1	14.0	+ve
Jar 6	288	348	58	20.1	0.009	20.2	1	15.0	-ve
Jar 7	288	372	61	22.7	0.017	15.2	1	14.0	-ve
Jar 8	288	339	62	20.8	0.049	17	1	14.0	-ve
Jar 9	288	344	58	26.7	0.007	13.5	1	15.0	-ve
Jar 10	288	362	61	26.4	0.398	11.2	1	15.0	+ve
Jar 11	288	329	62	20	0.416	16.1	1	15.0	+ve
Jar 12	288	337	63	17.2	0.217	18.4	1	16.0	+ve
Jar 13	288	391	61	19.1	0.169	17.8	1	14.0	+ve

Table-10: Methane Production at 10 deg C

Jar	Temp (K)	Gauge Pressure (kPA)	Gas Composition (vol %)					Gas volume (Ltr)	Flame Test
			CH4	CO2	H2S	N2	H2		
Jar 5	283	224	48	26	0.268	24.7	1	14.0	+ve
Jar 6	283	208	59	22.4	0.0008	17.5	1	15.0	-ve
Jar 7	283	212	51	28	0.012	19.9	1	14.0	-ve
Jar 8	283	209	52	25	0.044	21	1	14.0	-ve
Jar 9	283	224	58	28.5	0.006	12.4	1	15.0	-ve
Jar 10	283	232	44	38.7	0.346	15.7	1	15.0	+ve
Jar 11	283	219	59	22	0.408	19.9	1	15.0	+ve
Jar 12	283	241	61	18.4	0.206	19.2	1	16.0	+ve
Jar 13	283	231	55	30.6	0.169	12.8	1	14.0	+ve

Further observation at even 5 and 0 deg. C showed that Methane production constituted of an average of 52% in the jars with a low CH_4:CO_2 ratio but a final table could not be developed due to leakage development in the prototype digesters. As seen in Figures 4-1 and 4-2 obvious fact that gas pressure and methane production dropped with temperature drop under mesophilic bacterial decomposition.

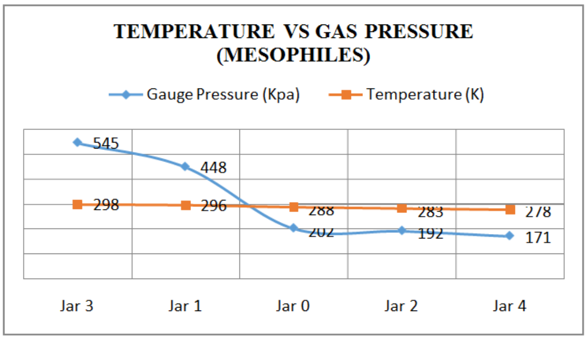

Fig-1: Temperature VS Gas Pressure (Mesophiles)

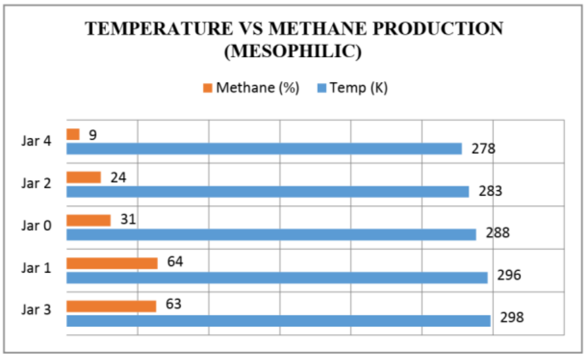

Fig-2: Temperature VS Methane Production (Mesophilic)

Comparative Production of Methane

The main purpose of this was to see the performance of Psychrophiles at high temperature (25 deg.C), optimal temperature (15 deg. C) and lo temperature (10 deg. C). It was seen that collected sampled psychrophiles exhibited either higher or similar methane production potentional at 25°C. Jar 2 here was the prototype digester maintained at 25°C under mesophilic conditions.

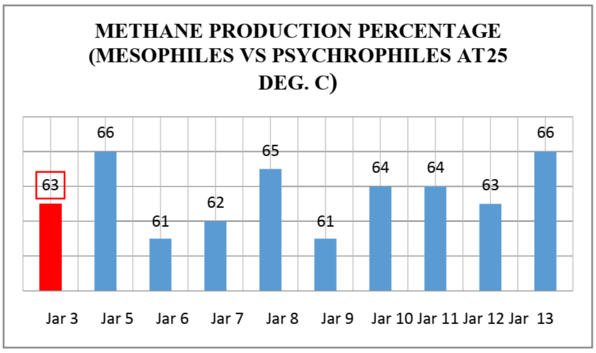

Fig-3: Methane Production Percentage (Mesophiles vs Psychrophiles at 25 deg. C)

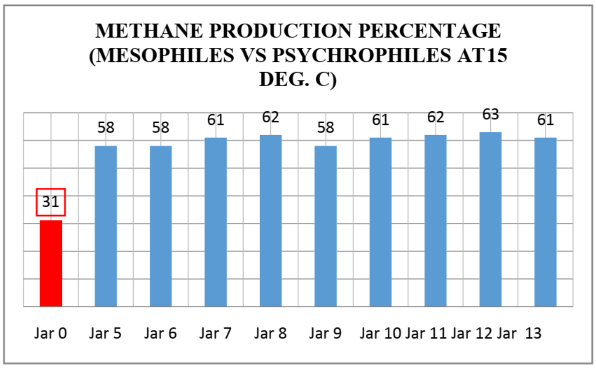

Fig-4: Methane Production Percentage (Mesophiles vs Psychrophiles at 15 deg. C)

As seen in Figure-4, at 15 deg. C which is considered the optimal temperature for Psychrophiles, the methane content was in usable and good range throughout the prototype digesters. On the contrary, mesophilic activity dropped in Jar 0 at the same temperature with the methane percentage dropping to 31. A feeble positive flame test was observed.

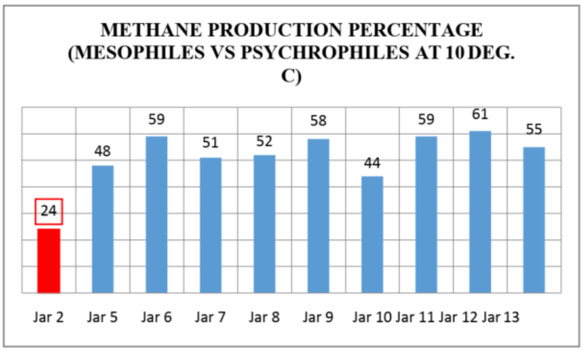

Fig-5: Methane Production Percentage (Mesophiles vs Psychrophiles at 10 deg. C)

It was seen that methane production was relatively high even at 10 deg. C. However, it was still lower than the production in mesophilic temperature range.

Assumptions

Due to the limitation of the gas analyzer, it is assumed that, the composition of biogas derived from various prototype digesters consists of 1% of Hydrogen.

The partial pressure of each constituents of the gas was calculated from the Dalton's Law of Partial Pressure and the mass of each constituent was calculated by using ideal gas equation which is

$$PV = mRT$$

Where,

P is pressure in kPa
V is volume in m3
m is mass in kg
R is gas constant in KJ/kg K
T in temperature in Kelvin

The values of gas constant of various gases are shown below:

Table-11: Gas Constant Values for Constituent Gases in Biogas

Gas	Gas Constant (J/kg K)
Methane	518.3
Carbon di-oxide	188.9
Hydrogen sulphide	244
Nitrogen	297
Hydrogen	412

The calculated partial pressure and overall gas constant of each constituent gas from the prototype digester is shown below:

The gas constant value of the composition mixture was calculated by using the formula

$$R = \frac{R1 * M1 + R2 * M2 + R3 * M3}{M1 + M2 + M3}$$

Where,

R = overall gas constant
R1, R2, R3 = Individual gas constant
M1, M2, M3 = Mass of Individual gas

Table-12: Partial Pressure and Gas Constant Values ofobtained gas from prototype digesters

	Temperature (Kelvin)	Pressure (KPa)	Gas Composition (vol %)					Volume of gas in Jar	Partial Pressure (kPa)					Mass (g)					Total Mass (g)	Gas Constant (J/kg K)
Jar			CH_4	CO_2	H_2S (ppm)	N_2	H_2		CH_4	CO_2	H_2S	N_2	H_2	CH_4	CO_2	H_2S	N_2	H_2		
Jar 1	298	450	53	32	853	13.1	1.0	15.0	238.5	144.0	3.8	59.2	4.5	12.276	12.279	0.00675	1.318	0.0183	25.9	350.7
Jar 2	283	172	28	35	607	35.4	1.0	15.0	48.2	60.2	1.0	60.9	1.7	1.379	5.912	0.00138	3.845	0.0074	11.1	267.1
Jar 3	283	228	48	26	268	24.7	1.0	14.0	109.4	59.3	0.6	56.4	2.3	5.372	4.325	0.00036	2.489	0.0098	12.2	356.2
Jar 4	283	182	8	22	10	69.0	1.0	15.0	14.6	40.0	0.0	125.6	1.8	0.119	2.472	0.00000	15.459	0.0078	18.1	283.7
Jar 5	278	107	5	14	11	80.0	1.0	15.0	5.4	15.0	0.0	85.6	1.1	0.028	0.599	0.00000	12.438	0.0047	13.1	292.6
Jar 6	278	144	34	16	228	48.8	1.0	14.0	49.0	23.0	0.3	70.2	1.4	1.733	1.053	0.00017	6.223	0.0063	9.0	327.0
Jar 7	278	93	8	16	184	74.8	1.0	15.0	7.4	14.9	0.2	69.6	0.9	0.062	0.680	0.00007	9.457	0.0041	10.2	291.2
Jar 8	278	111	18	22	43	59.0	1.0	14.0	20.0	24.4	0.0	65.4	1.1	0.374	1.535	0.00000	7.009	0.0048	8.9	287.8
Jar 9	278	78	1	10	4	88.0	1.0	15.0	0.8	7.8	0.0	68.6	0.8	0.001	0.223	0.00000	10.973	0.0034	11.2	294.9
Jar 10	298	426	46	38	347	14.7	1.0	14.0	196.0	161.9	1.5	62.4	4.3	8.754	16.392	0.00106	1.550	0.0173	26.7	303.3
Jar 11	278	155	24	33	418	41.6	1.0	14.0	37.2	51.2	0.6	64.5	1.6	0.929	4.821	0.00060	4.869	0.0068	10.6	267.4
Jar 12	278	128	21	28	195	49.8	1.0	15.0	26.9	35.8	0.2	63.8	1.3	0.588	2.866	0.00011	5.768	0.0056	9.2	277.6
Jar 13	298	404	43	32	168	23.8	1.0	14.0	173.7	129.3	0.7	96.3	4.0	7.255	11.024	0.00024	3.889	0.0165	22.2	315.7

Total Solid (TS) value

Total solid contained in a certain amount of materials is usually used as the material unit to indicate the bio-gas producing rate of materials.

1 kg TS of cattle dung produces 0.25 m3 of biogas at 25°C. Again from ideal gas equation for biogas, Gas constant for biogas = 0.518 kJ/ kg K

For 1 atm pressure, 1 kg TS of cattle dung produces 0.164 kg of biogas.

As Jar 1, Jar 10 and Jar 13 were kept in room temperature, it can be seen that the amount of biogas produced is 25.9 g, 26.7 g and 22.2 g respectively.

The total amount of organic feed in Jar 1 was 3 kg.

So, $TS * 3\ kg * 0.164 = 25.9 * 10^{-3}\ kg$

So, TS = 5.26 % for the organic feed which was put in the prototype digesters. In the prototype digesters, Hydraulic Retention Time was kept to be 55 days. Design of Digester of Volume 2 m3

V = 2 m3

Cross –section of a digester:

a) Volume of gas collecting chamber: Vc
b) Volume of gas storage chamber = Vgs
a) Volume of fermentation chamber = Vf
b) Volume of hydraulic chamber = Vh
c) Volume of Sludge layer = Vs

Table-13: Geometrical Dimension of the Cylindrical Shaped Biogas Digester Body

For Volume	For geometrical dimensions
$V_c \leq 5\% V$ $V_s \leq 15\% V$ $V_{gs} + V_f = 80\% V$ $V_{gs} = V_h$ $V_{gs} = 0.5\ (V_{gs} + V_f + V_s) * K$ Where K = gas production rate per m3 digester volume per day	$D = 1.3078 * V^{1/3}$ $V_1 = 0.0827\ D^3$ $V_2 = 0.05011\ D^3$ $V_3 = 0.3142\ D^3$ $R_1 = 0.725\ D$ $R_2 = 1.0625\ D$ $f_1 = D/5$ $f_2 = D/8$ $S_1 = 0.911\ D^2$ $S_2 = 0.8345\ D^2$

For V = 2m3
D = 1.65 m

Similarly, V3 = 3.14 * D2 * H/4

- H = 0.66 m
- f1 = D/5 = 0.33 m
- f2 = D/8 = 0.21 m

- R1 = 1.2 m
- R2 = 1.75 m
- V1 = 0.37 m3
- Vc = 0.1 m3

Vgs = 0.5 (Vgs + Vf+ Vs) * K
= 0.5 *(0.8 * 2 + 0.15 * 2) * 0.4

= 0.38 m3

Also, Vgs = 50% of daily gas yield
= 0.5 * TS * gas producing rate per kg TS
= 0.5 * TS * (0.011/(3*0.0526))

At 10˚C, 1 atm pressure, the biogas production rate when the sample is added, Production rate = 0.067 kg/kg TS

Production rate (volume) = 267 * 283*0.067/100000 = 0.05 m3 Gas production rate per kg TS = 0.05 m3/ kg TS TS required = 15.2 kg TS

Considering 49 % of total solid in available discharge, So, total discharge required = 15.2/0.49 = 30 kg per day 30 kg per day of organic wastes is required per day Considering hydraulic retention time of 55 days, Vgs + Vf = Q . HRT Q = 1600/55 = 30 kg

So, this is confirmed by the digester volume as well that 30 kg organic feed is required per day for the given dimension of the cylindrical digester of 2 m3 volume.

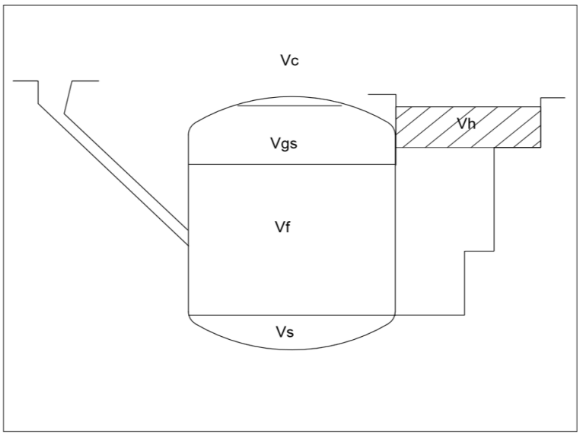

Fig-6: Cross Section of Digester

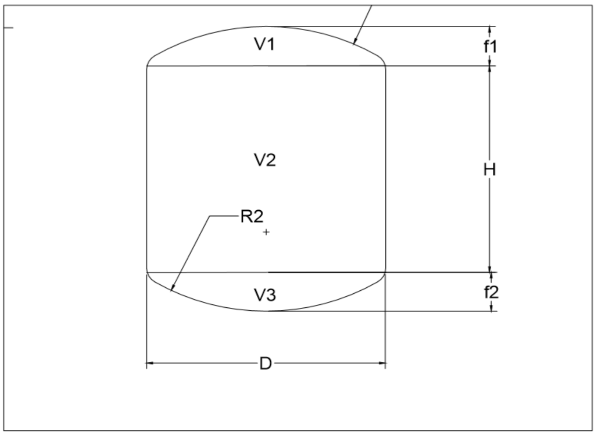

Fig-7: Geometrical Dimensions of Cylindrical Shaped Biogas Digester Body

CONCLUSION

The samples collected from aforementioned high-altitude lakes were tested in relatively macro scale by formation of prototype digesters which were kept at varying temperatures. The samples from Gokyo Lake showed indication of presence of some form of psychrophilic methanogens as it produced more biogas relative to the prototype at the same temperature but without any samples. It was found that some samples collected from the site had indication of presence of organic decay in it whereas all of the sediments of the lake did not have such indication. The methane production potential of the samples along with organic wastes showed that for proper biogas generation in a 2m3 digester volume, 30 kg of organic wastes is required, which is quite high. Also, the due to low pressure developed, the analog pressure gauge was difficult to use and digital pressure gauge was required. This limited the study of pressure at hydraulic retention time of 55 days.

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