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Experimental Investigation of Novel Fixed Dome Type Biogas Plant using Gas Recovery Chamber in Rural Areas of Pakistan

Salman Ahmad*‡, Samia Razzaq*, Mirza Abdullah Rehan*, Muhammad Ali Hashmi*, Shoukat Ali*, Zafar Abbas*, Muhammad Shurjeel Amjad*, Umair Mehmood*

*Mechanical Engineering Department, Pakistan Institute of Engineering and Technology, Multan, Pakistan

(engr.salmanahmad106106@gmail.com, samiaa.razzaq@gmail.com, engr.mirzaabdullah58@gmail.com, alihashmi35@gmail.com, engr.shoukat.khan@gmail.com, zbaloch189@gmail.com, Shurjeelamjad03@gmail.com, Chumair259@gmail.com)

‡ Corresponding Author; Salman Ahmad, Pakistan Institute of Engineering and Technology Multan, Pakistan,

Tel: +92 3069325892, engr.salmanahmad106106@gmail.com

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Abstract- Energy is the lifeblood of modern civilization. Pakistan is facing an acute energy crisis due to dependence on fossil fuels having economical as well as environmental consequences. Biogas is a viable source of energy to tackle the problem of this energy crisis in agriculture-based developing countries like Pakistan. A 6 m^3 capacity novel fixed-dome digester was installed and operated at variable temperatures (30 to 42 °C) in order to assess its potential, typically of the Southern Punjab, Pakistan, from July 2018 to August 2018 and different parameters like temperature, pH and gas production were recorded. The present study is designed to enhance the gas production by using the gas recovery chamber. Gas recovery chamber is a small digester that requires less initial cost compared to two-stage digestion. Moreover, the boost in fermentation time of bacteria in acetogenisis and methanogenisis is about 5 days using the gas recovery chamber. It is clear from the results that gas recovery chamber in the fixed dome biogas plant increased the gas yield from 3.24 to 3.71 m^3. Due to this technique, an increase in 21.5% gas production achieved as compared to the conventional biogas plant, simultaneously decreasing the payback period of this plant (19 months to 15 months). This recovery chamber utilizes maximum methanogens bacteria for fermentation under climatic conditions of Pakistan. This technique is the feasible solution to the increasing demand and limited conventional gas resources of Pakistan. This investigation shows recent improvement in the anaerobic digestion processes that have led to greater biogas production.

Keywords Energy crisis, cow dung, anaerobic digestion, hydraulic retention time, payback period.

1. Introduction

The evolution of the world economy, the continuous thriving of human needs, industrial as well as technological development have led to an increased demand for energy and consumption of fossil fuels [1]. However, current industrial production relies on relatively old and inefficient strategies and low production yields, which have decreased their competitiveness with fossil-based alternatives [2]. Fossil fuels have been a major contributor to greenhouse gases. The amounts of these gases can be reduced if biomass such as biogas is used for cooking purpose [3].

Biogas has emerged as a viable renewable technology to convert agricultural, animal, industrial, and municipal wastes into energy. Biogas is a kind of renewable energy and one of the most widely distributed and easily accessible energy forms. It has currently become the main direction for renewable energy development [4]. The production of bio energy from cattle dung has the potential to reduce fossil fuel usage. The number of biogas facilities around the world has risen dramatically, increasing demand for feed stocks [5]. Organic waste and sludge samples were collected from the dairy farm, mixed in desired ratios, and analyzed in triplicate for potential biogas yield [6]

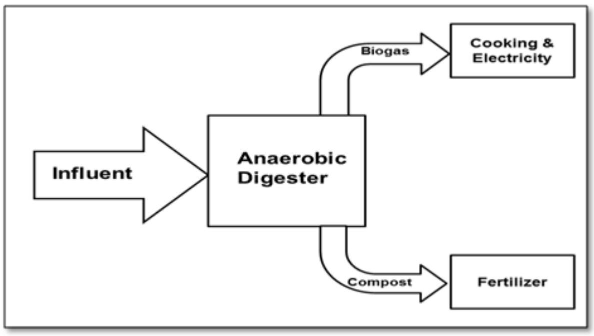

Fig. 1. Anaerobic digestion influent and output streams

Pakistan is facing an energy crisis of electricity, causing load shedding several hours per day due to the adherence to conventional energy resources having quantitative and environmental limitations [7]. Pakistan's government is spending more than 14.5 billion US dollars to import crude oil in order to fulfill the energy gap every year. Pakistan takes the opportunity to have more than half of its population living in rural areas [8]. Pakistan has an abundant amount of waste produced in the form of cattle dung, poultry waste, and municipal waste. A large number of official databases and literature have been surveyed and analyzed to address the characterization of the biogas (AD-based) digestate and the potential benefits of biogas-to-power in Pakistan [9]. Biogas potential from live stokes waste in district Khanewal can be seen in table 1:

Table 1. Biogas production potential in district Khanewal

Tehsils	Buffalos & Cows	Dung Produced (kg/day)	Biogas Production Potential (m^3/day)
Khanewal	232632	3489480	157026
Jahanian	123723	1855845	83513
Kabirwala	391853	5877795	264500
MianChannu	337436	5061540	227769
Total:	**1085644**	**16284660**	**732808**

Rajendran [10] discussed that biogas production depends on different factors including substrate, pH, temperature, hydraulic retention time (HRT), loading rate, mixing and C/N ratio. Usually, the size of these digesters ranges between 1 to 150 m^3. The common designs of digester include fixed dome, plug flow and floating drum type**.** Kress [11] studied the impact of reduced mixing time in a full-scale biogas reactor from 10 to 5 and 2 minutes in half an hour on the distribution of acetic acid.

Kress [11] investigated the performances of the acedogenic phase and the methanogenic phase significantly decrease at a lower temperature of 20℃ thus increasing HRT of biogas. However, during winter conditions, the digester temperature must be maintained above 25 °C for viable gas production round the year. Safa evaluated the performance of fixed dome Biogas unit (Chinese's model), with a capacity of 1.8 m3 gas/day and having 50 days retention time. After mixing the slurry by designed agitator, the average of biogas production was increased about 42%. Nandi [12] evaluated the effect of mixing on anaerobic digestion of cow dung in lab-scale experiment at 35 °C. The effect of continuous mixing (mixing for 5 minutes with interval of 15 minutes at 100 rpm) on methane production was investigated in three lab-scale continuously stirred tank reactors. An increase in 2.20 % and 18.85 % biogas production was observed [13].

. RM rezaei [14] used computational fluid dynamics (CFD) to discover a satisfactory mixing stirrer for biogas plant and it was observed that six-blade turbine impeller to be most effective for homogeneous mixing. Iqbal [15] evaluated the production capability of biogas with co-digestion of cow manure and kitchen waste, 0.8 - 5.5 times increment was observed as compared to the digestion with dairy manure alone. Nwofe [16] studied the influence of nitrogen source on biogas yield from cow dung and rice husk. The heavy metals (Ni and Zn) increased the biogas yield while Fe2+ (100 ppm) showed no effect. The use of guano indicated more biogas production rate in both feedstocks compared to poultry droppings. Sam [17] designed solar heating biogas fermentation system with volume capacity of 6 m^3. Finally, a U-tube collector system was carried out for 5 months experiment, to find out matching relationship between the solar collector system and biogas fermentation system. Gupta [18] investigated the use of solar heating to heat the digester to 35 °C improved the biogas production by 50% compared to psychrophilic digestion (below 20^{o}C). Durdica [19] developed a method for pretreatment of different substrates cow dung, agriculture waste and kitchen waste using electro portion (EP) technique for the purpose of improving the biogas production.

Li experimentally investigated the performance of two phase pressurized biofilm system at different pressures from 0.3 to 1.7 MPa. Biogas having highest calorific value of 36.2 MJ/m^3 at pressure of 1.7 MPa was achieved. Wang [6] investigated the effect of temperature on biogas production and the bacteria structure in a two-phase anaerobic digestion reactor for co-digestion of cow manure and corn straw. Lemmer [20] evaluated lab scale pressurized anaerobic filter reactor in two phase process under wide range of operating parameters. An increase in hydraulic retention time (HRT), which results in higher biogas production. Kurniawan [21] presented the performance of two stage anaerobic digestion method using reverse membrane bioreactors. An increase in biogas production was achieved. Al-addous [22] suggested a submerged anaerobic membrane bioreactor in a two phase anaerobic digestion system with improved methane production. Youngsukkasem [23] introduced a new design of multi-layer membrane bioreactors (MMBR) and entrap methane-producing microorganisms in the bioreactor in order to increase biogas production.

Anmbrs [24] reviewed the idea of anaerobic membrane bio-reactor (An MBR) in fixed dome type biogas plant as a feasible solution that overcame the disadvantages of conventional wastewater treatment. Prapinagsorn [25] studied two-stage fixed dome type biogas plant by using co-digestion of cow dung, grass and silage as a feedstock. As a result, methane yield obtained was 169.87 and 141.33 mL CH4/g, respectively. Lemmer [26] investigated if the efficiency of the novel two-stage fixed dome biogas plant could be further increased by integrating a water scrubbing system into the pressurized methane reactor. Because of this study, the methane content in the biogas were increased from 75 molar percent (mol %) to 87 mol%. The pH value of the substrate in the reactor was increased from 6.5 to 6.7 simultaneously. Wikandari [27] investigated the effect of recirculation in biogas production from citrus waste for toxic feedstock in two-stage fixed dome anaerobic digestion. The result showed that the reactor with effluent recirculation produced a higher methane yield (160–203 mL/g) compared to other, without recirculation (66–113 mL/g). Yeqing [28] investigated the effects of using two-stage pressurized biofilm (TPPB) system in fixed dome type biogas plant. By using pressurized biofilm anaerobic reactor pressure increased from 0.3 MPa to 1.7 MPa, due to this increased in pressure biogas with higher calorific value 36.2 MJ/m^3 was obtained at a pressure of 1.7MPa. However, the performances of the acidogenic and the methanogenic phases could significantly decreased at a lower temperature of 20 ^{o}C. Consequently, the methane-forming bacteria are more easily affected by the process conditions and require a longer retention time [29]. Moreover, the increasing time of bacteria in methanogenic phase is about 5–6 days by using gas recovery chamber.

From the extensive literature review, it is quite explicit that a significant amount of methanogens bacteria were go out of digester without producing biogas in a conventional fixed dome type biogas plant. Therefore, this research has been done to utilize acetogens and methanogens bacteria's in recovery chamber to enhanced methane contents as well as biogas production.

The main objectives of this study were: (1) to evaluate biogas production performance by adding gas recovery chamber system in biogas plant, using cow dung as feedstock. (2) to investigate the performance of novel biogas digester using gas recovery chamber with different parameters like temperature, pH and hydraulic retention time (HRT). (3) to reduce payback period of conventional fixed dome type biogas digester.

2. Materials and Methods

The research was carried out in district Khanewal, Pakistan (30.286415°N, 71.932030°E). Feedstock composition is one of the major factors that affect the production of biogas. High yields of methane depend mainly on the substrates used as feeding material. In this work, cow manure was used as feeding material [30].

2.1. Description of Biogas technology in target area

In current study, small-scale Nepalese fixed dome type biogas plant, at 88/10R district Khanewal. The questionnaire survey was carried out with the owners of small-scale biogas plants from July to August 2018. Fixed dome type biogas plants are unheated and usually built underground, in order to minimize the temperature fluctuations. It also saves ground space [31]. The biogas produced is accumulated at the upper part of the digester and the difference between the slurry inside the digester and the digestate in the compensation tank creates a gas pressure [32]. The slurry flows into the gas recovery chamber to increase gas production by about 21.5%. Moreover, the fermentation time of bacteria in acetogens and methanogens was increased about 5 days using the gas recovery chamber. The average summer temperature in Khanewal is around 40^{o}C (mesophilic conditions), best suited for the bacterial fermentation. However, during winter the temperature is in the range of 15–25 ◦C, which would cause lower biogas production. The numerous factors pertinent to the design and operation of fixed dome type anaerobic digesters using gas recovery chamber were determined to ensure the maximum efficiency and cost-effectiveness of a digester provided its respective operating conditions [33].The second-stage, which is dedicated to methane production has an optimum pH of 7–8. The accumulation of VFA produced during acedogenes is in the first-stage generally decreases the pH below the optimal value [27]. It was observed in the survey that a significant amount of methanogens bacteria go out of the digester through overflow tank without producing biogas.

Region	Gas Production (m^3)	Plant Size (m^3)	Consumers	Animals	Daily Feed (kg)	HRT (days)	Temperature (°C)
Multan	25	50	27	40	1250	40	30
Multan	35	70	1	55	1750	40	30
Bahawalpur	35	70	37	55	1750	35	34
Bahawalpur	12.5	25	15	20	625	35	34
Bahawalpur	3	6	5	5	150	35	34
Bahawalpur	12.5	25	20	22	625	35	34
Bahawalpur	17.5	35	25	28	875	35	34
Bahawalpur	10	20	14	15	500	35	34
Khanewal	50	100	70	80	2500	40	30
Duniyapur	7.5	15	10	12	375	40	30
Duniyapur	7.5	15	10	12	375	40	30
Duniyapur	12.5	25	20	20	625	40	30
Bahawalpur	10	20	14	15	500	35	34
Bahawalpur	12.5	25	20	20	625	35	34
Bahawalpur	25	50	30	40	1250	35	34
Kabirwala	12.5	25	20	20	625	40	30
Khanewal	3	6	5	5	150	40	30
Lodhra	10	20	14	15	500	38	32
Lodhra	10	20	14	15	500	38	32
Kabirwala	6	12	3	10	300	40	30

Fig. 2. Installed biogas plants in south Punjab, Pakistan

2.2 Substrate and inoculums

Cattle dung was collected from a dairy farm located in the vicinity of Khanewal, Pakistan. A homogeneous mixture was prepared with dung to water ratio of 1:1 [34]. Using the given ratio, 75 kg of dung was mixed with an equal quantity of water to prepare the required feed.

Table 2. Mixture composition for biogas production

Waste	Mass of Dung (kg)	Mass of Water (kg)	Mix Ratio
Cow dung	75	75	1:1

2.3 Experimental set-up

This experiment was carried out in July and August 2018 at Khanewal, Pakistan. The diameter of the digester is 98 inches, height is 37 inches and inlet pipe put at distance of 12 inches. Inlet tank diameter is 18 inches and height is 24 inches. The width of outlet tank is 50 inches, length is 64 inches and height is 24 inches. The outer diameter of the gas recovery chamber is 25 inches and height is 37 inches [30].

Excavation of Digester | Wall of Digester | Fixed dome Digester

Inlet tank | Overflow tank | Gas recovery pipe

Fig. 3. Pictorial views of installed biogas plant

2.4 Gas recovery chamber and cell encasement

An anaerobic digestion process, for treating cattle dung mixture, was carried out in a small scale two-phase anaerobic digestion reactor, as shown in Figure 1. The first stage study was done by running semi-continuously with a working volume of 6000 L and an HRT of 40 days.In the second stage, the experiment was carried out in repeated batches. A fixed-dome plant comprises of a closed, dome-shaped digester with an immovable, rigid gas-holder and a displacement pit, also named “compensation tank”. The gas is stored in the upper part of the digester. When gas production starts, the slurry is displaced into the gas recovery chamber [35]. The purpose of encasement is to retain a high cell concentration of methanogens bacteria inside the gas recovery chamber, without flowing through the overflow chamber.

2.5 Design criteria and calculations

In most bioreactors, the rate of gas production depends on time, seasonal temperature and substrate quality [36]. The fixed dome type portable biogas plant is designed to have a daily production capacity between 3.71 – 3.75 cubic meter of biogas. It is achieved through conversion of cattle dung obtained from five buffaloes/cows (fermentable organic matter) into combustible biogas and fully mature organic manure as a byproduct. On average, one buffalo excrete about 15kg manure per day. Almost 2.5 KWh electrical power can be generated from 1m3 of biogas [37]. On average five cattle’s will excrete about 75 kg manure per day that is equivalent to 3m3 (40 m3 biogas produced from 1000 kg biomass i.e. 0.040 m3/kg). The ratio of dung and water used forthis product is 1: 1 i.e. 75 kg of each dung and water. Total input per day become 150kg. Then,total input for 40 days will become 6000kg (40days x 150kg = 6000 kg approx per month).

The required digester volume was determined as follows:

$$V_{gs} + V_f = Q \times R \quad (1)$$

Total influent to be digested daily was calculated by Equation:

$$Q = W_L + V_w \quad (2)$$

Hydraulic retention time (HRT) refers to the mean length of time that the substrate remains in a digester [34]. The mathematical formula for the retention time is as follows:

$$R = V/F \tag{3}$$

The gas production from a semi-continuous (daily) feed biogas plant is given by[23]:

$$\text{Gas Production} = \text{Substrate Feed} \times \text{Sp. Gas Production } (0.04\ m^3/kg) \tag{4}$$

Volume of daily biogas produced using gas recovery chamber is given by:

$$\text{Gas Production} = \text{Substrate Feed} \times \text{Sp.Gas Production } (0.0075\ m^3/kg) \tag{5}$$

For low substrate concentration, this equation is valid.

$$R_s = Q_{max} \text{ x } S_x/(K+S) \tag{6}$$

$$R_s = Q_{max} \text{ x } X \tag{7}$$

Payback period of biogas plant is calculated by:

$$\text{Period} = \text{Actual plant cost / Total profit} \tag{8}$$

For high substrate concentration, it becomes as follows:

Theoretical biogas calculated using the equation for the cow manure ($0.04m^3/kg$) is shown in the table 3

2.6 Novel Process Diagram

The experimental procedure of the anaerobic digestion using gas recovery chamber is shown in figure 3. First of all 75 kg of cow dung was collected from cow shed, mixed with an equal proportion of water and prepared homogeneous mixture in inlet tank. This homogeneous mixture was feed into the two stage anaerobic digestion by using gas recovery chamber. In this technique, the methogenous becteria first enter the gas recovery chamber before leaving through over flow chamber. By using this technique, enhancing a significant amount of gas production then this slurry flows to overflow tank which is used as a fertilizer. We used check valve or non-return valve which allowed biogas to flow in one direction and avoided the back pressure of the gas [31].

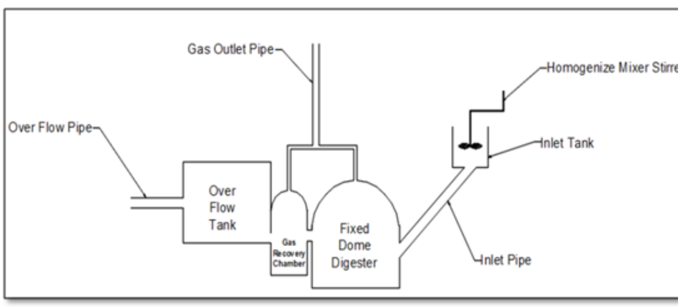

Fig. 4. Schematic diagram of the domestic level biogas plant using gas recovery chamber

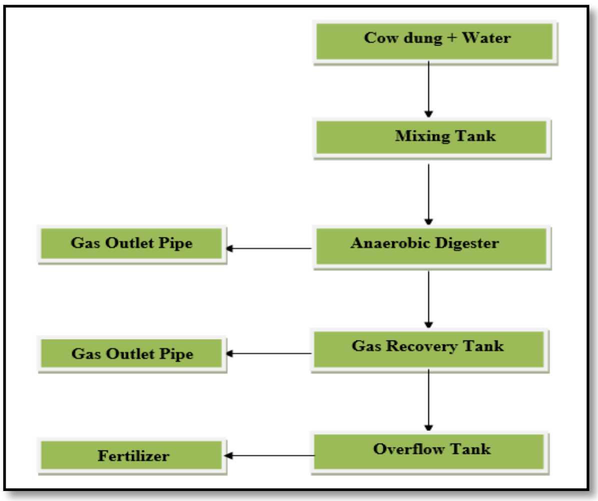

Fig. 5. Flow chart of biogas production using gas recovery

Table 3. Biogas production using gas recovery chamber and theoretical analysis

Plant Size (m^3)	Daily Feed(1:1) (liter)	Gas Production (m^3)	Gas Recovery Chamber (m^3)
=150 kg x40	= 6000/40	= 75 kg x 0.04(m^3/kg)	= 100 kg x0.0075(m^3/kg)
= 6000 kg	150kg/day	=3m^3	= 0.75 m^3
As 1000kg = 1 cubic meter Plant Size = 6m^3			Total Biogas Production =3.75 m^3

2.7 Plant Cost Using Gas Recovery Chamber

In past, the main reasons for under consideration of these plants are that the biogas plants have less profitability and long pay back periods (over 2.5 years). By including the gas recovery chamber,the payback period is 1.26 years and 21.5 % increase in gas production achieved. Due to the rapid increase in requirements of natural gas in Pakistan, these plants can be very useful for solving the current energy crisis of Pakistan.

2.8 Payback Period

In the present case, the payback period is calculated on the basis of two main products:

- Bio gas
- Bio Fertilizer

Table 4. Plant cost using recovery chamber

Materials	Unit	Quantity	Per unit cost	Total cost
Bricks	No.	2600	8	20800
Cement	No.	31	580	17980
Gravel	Cu Ft	100	35	3500
Sand	Cu Ft	110	24	2640
Pipe	Inch	7	70	490
Pressure Gauge	Milli bar	1	2500	2500
Iron bars	Kg	20	85	1700
Pipe	Feet	8	225	1800
Labor Skilled& Unskilled	Rs	15	1600	24000
Fitting Materials Gas Recovery Chmaber Other Cost	Rs Rs Rs	2 1 --	3000 9115 4000	6000 9115 4000
Total Plant Cost				85410

Table 5. Payback Period calculation for Biogas plant

Biogas Profit	Fertilizer Profit	Payback Period	
Daily Gas Production (using gas recovery chamber)	Daily Fertilizer	=85480/(13500+54000)	
= 3.75 m^3	Production = 75kg		
= 1350 m^3	= 75x12x30 = 27000kg	Payback Period = 1.266 year	

3. Results and Discussion

Table 6. Biogas production comparison

HRT (Days)	Sample Appearance	Biogas Production Using Gas Recovery Chamber (m^3/day)	Biogas Production Using Gas without Recovery Chamber (m^3/day)
1-7	Biogas produced in very small quantity	0.015	0.015
8-14	Biogas produced in very small quantity	0.034	0.032
15-21	Biogas produced in small quantity	0.109	0.091
22-28	Biogas produced in small quantity	0.93	0.850.
29-35	Biogas produced in good quantity	1.90	1.74
36-40	Gas collection tank is almost full	2.95	2.76
41-45	Gas collection tank is full	3.71	3.24

This study is evaluated on novel fixed dome type biogas plant in Khanewal, Pakistan and aimed to identify the parameters that useful to enhance biogas production. By using the gas recovery chamber in 6m^3 plant 75kg of cow dung was mixed with an equal quantity of water (1:1) to produce 3.71m^3 of biogas per day. This amount of biogas is enough to fulfill the cooking needs of 8 people. In conventional biogas plants, the production capacity of the gas is only 3m^3 and can only fulfill the cooking needs of 6 people.

3.1 Observations of the Experiment

Gas production of this plant was initiated after 10 days of initial dung feed in the digester and reached the peak level in the sixth week. The details of biogas production with HRT are given in table 6.

3.2 Effect of Gas Recovery Chamber on Biogas Production

The production of biogas during anaerobic digestion is strongly affected by the hydraulic retention time; HRT is the average duration of time that a sample remains in the digester. Increase in HRT directly affects the gas production. Daily biogas production was assessed for HRT of 45 days and dilution rates were kept 1:1 at each retention time. At the beginning of the digestion's 14 days, a relatively low yield of biogas 0.034 m^3 was observed because of insufficient methanogens bacteria. The total biogas yield rapidly increased up to 2.95 m^3 on day 40 and then gradually stabilized at 3.69 m^3 on day 45 using gas recovery chamber. The biogas yield per kilogram was about 0.04 m^3. By using gas recovery chamber, 21.5 % gas production was increased in comparison to single stage conventional biogas plant whose HRT is 45 days. The variation of gas production with different HRT using gas recovery chamber has can be seen in figure 5.

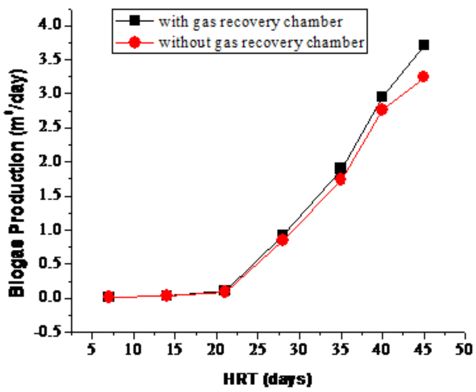

Fig. 6. Variation of Biogas Production with HRT

By using gas recovery chamber, 3.71 m^3 biogas obtained per day with HRT of 45 days in 6 m^3 biogas plant. According to Pakistan climate, 5 days of HRT was increased using recovery chamber. Due to this, biogas production was increased and maximum methonogenous becteria were utilized. In convential biogas plant, 3.24 m^3 of biogas produced because sufficient amount of acetogenisis and methanogenisis bacteria went out off the overflow tank without producing biogas. During winter, when fermentation process slows down, gas recovery chamber optimizes the biogas production.

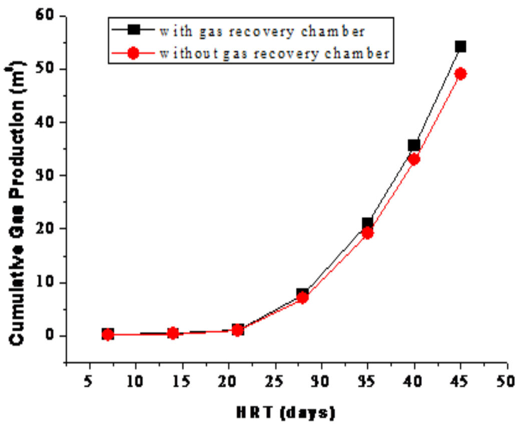

Fig. 7. Variation of Cumulative Biogas Production with HRT

3.3 Effect of Gas Recovery Chamber on Digester Temperature

The production of biogas during anaerobic digestion is strongly affected by the temperature. In case of mesophilic digestion, temperature range should be maintained between 20 and 38°C. Mesophilic digestion offers more benefits in terms of specific growth of bacteria and less ammonia inhibition than psychrophilic. An increase in digester temperature above 55^{o}C results decrease in methanogens bacteria. The gas production decreases sharply below 20˚C and almost stops at 10˚C. This study was carried out in summer season where average T_{amb} of Khanewal, Pakistan is about 40^{o}C which is optimum for biogas production. The graph between ambient and digester temperature with HRT is shown in figure 8.

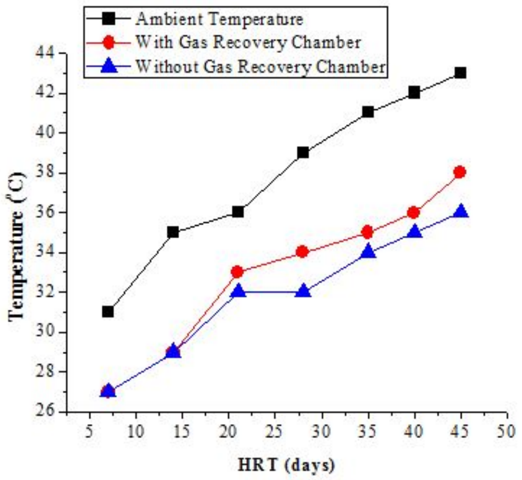

Fig. 8. Variation of Temperature with HRT

From the results the maximum cumulative biogas production was achieved at 35 °C, while overall maximum methane yield potential was obtained at 39 °C [38]. By using gas recovery chamber, HRT increases about 5 days, and the digester temperature increases. Thus, enhancing the methane and biogas yield subsequently. Using recovery chamber, digester temperature was increased to 38°C, which is optimum value for maximum biogas production. On the other hand, this temperature is achieved a maximum value of 35°C without using gas recovery chamber. At this temperature, fermentation of methanogens bacteria does not complete. Due to this reason, biogas production decreased compared to novel fixed dome plant with gas recovery chamber. Fig. 7 shows the details of the variations in temperature with time.

3.4 Effect of Gas Recovery Chamber on pH

The pH (Potential hydrogen) of the input mixture plays very important role in methane formation. The acidic condition is not favorable for methanogenic process; usually the pH for fermentation bacteria is around 7-8. The easiest way to find pH is by using pH paper. After initial feeding the plant with dung, the pH decreased to 6.9. By providing effective hydrolysis and acedogenesis, then pH ranges in between 6.3 and 6.9. The pH value gradually stabilized at 7.0 and 7.2 at the end of stage acetogenesis. At the end of the methane fermentation stage pH value in between 7.2 and 8.0. In gas recovery chamber, the pH is reached to a peak value 8.1 which is much lower than that of stage I. This increased in pH also increased the buffer capacity and capability for methanogens during stage II. The variation of pH value with different HRT is shown in figure 8.

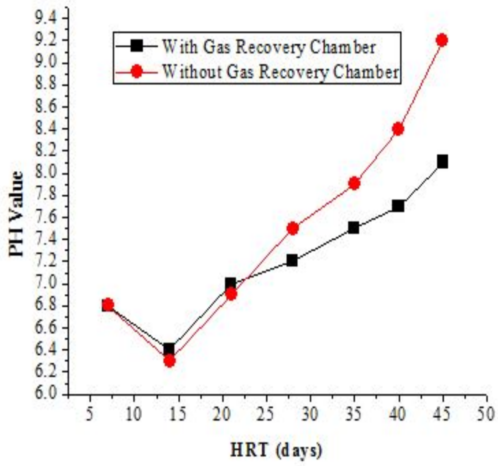

Fig. 9. Variation of PH with HRT

The results showed that pH=7 was most favorable for bacterial growth in the digester and produced better biogas yield as compared to the other pH values. 60.8% methane and 36.3% carbon dioxide was obtained at pH=7, which is the maximum methane yield as compared to other pH values. The lowest biogas yield and digestion's efficiency was obtained with the substrate of pH 5. By using gas recovery chamber, pH range remained in between 7-8 after hydrolysis; which decreased volatile solids (VS),total solids(TS) and CO_2 composition. This range is most favorable for methane as well as biogas yield. Without using gas recovery chamber, pH ranged in between 7-9 which increased VS(g/l), TS(g/l) and CO_2 composition and reduced biogas yield.

This biogas plant has the ability to convert bio-waste to green energy. Pakistan being an agricultural country and more than 50% population living in rural areas increases the scope of biogas plant in Pakistan. Using 6 m^3 fixed dome novel biogas plant with gas recovery chamber generates 3.71 m^3 biogas that is enough to fulfill the cooking and heating load of 8 persons in rural areas. This amount of gas can also be used to generate 4.3 KWh electricity by using gas-fired turbine. From the above discussion, it is clear that it has very useful real life applications.

4. Conclusion

Experimental investigation and theoretical calculations regarding the integration of a gas recovery chamber for gas production improvement in a novel two-stage anaerobic digestion system were achieved, and conclusions were made as follows:

1. The two-stage fermentation using gas recovery chamber system successfully ran for more than 60 days. Results

showed that HRT can significantly influence the biogas quality and production. 3.24 m^3 of methane yield is obtained under HRT of 40 days. On the contrary, this yield rises to 3.71 m^3 under HRT of 45 days.

2. A Semi continuous pilot-scale anaerobic digestion system was successfully developed to investigate the biogas yield by using gas recovery chamber (1:1 cow dung and water). An increase in 21.5% biogas yield for mesophilic digestion was observed. In addition, the payback period of biogas plant was decreased from 19 months to 15 months.

3. This recovery chamber is found to be very effective to provide a consistent biogas production, under the wide range of operating parameters (HRT, temperature, pH). This work could provide useful information on high quality biogas production form anaerobic digestion of cow dung using additional upgrading equipment. Nevertheless, the biogas yield obtained in this research was proved to be better than that of one-stage semi-continuous operation.

4. Due to rapid increase in requirements of natural gas in Pakistan, such plants can be viable option to solve the current gas issues.

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Nomenclature

V_w	Volume of water (kg).
V	Volume of digester (m^3).
F	Daily Feed (kg).
S	Limiting substrate concentration (%).
K	Half-life constant.
X	Concentration of bacterial cells (%).
Q	Total Influent (kg).
W_L	Daily waste load (kg).
R	Hydraulic Retension Time.
Q_{max}	Maximum substrate utilization rate (kg/day).