Effect of Buffalo Dung to the Water Ratio on Production of Methane through Anaerobic Digestion

ABDUL RAZAQUE SAHITO*, RASOOL BUX MAHAR**, AND FAROOQ AHMED***

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ABSTRACT

Generation of methane from animal dung through AD (Anaerobic Digestion) is the most feasible way to get energy from it. Pakistan has about 70 million heads of cattle and buffalos, and about 90 million heads of sheep and goats. The dung from these animals can overcome the energy crisis and can fulfill the future energy demands of Pakistan. In present study, buffalo dung is used as the substrate for anaerobic digestion process, whereas the production of methane was analyzed as the function of buffalo dung to water ratio. Six batch reactors with different buffalo dung to water ratios were incubated in the AMPTS (Automatic Methane Potential Test Setup) for 51 days. The highest methane production was observed from the buffalo dung to water ratio of 2.0 i.e. 226.4 NmL/gVS$_{loss}$, followed by 198.6 NmL/gVS$_{loss}$from the buffalo dung to the water ratio of 1.0. The suitable hydraulic retention time of the anaerobic digester treating buffalo dung was observed as 20 days.

Key Words: **Methane, Buffalo Dung, Water Ratio, Methane Potential Test, Digestate.**

1. INTRODUCTION

The increasing cost of fossil fuels and increased pollution due to their combustion, the utilization of the renewable energies have become an attractive and alternative energy systems in many countries worldwide. Regarding the Pakistan's primary energy supplyas shown in Fig. 1, more than 90% of itcomes from fossil fuels and about half of its supply comes from natural gas. Pakistan produces about 42.9 billion cubic meters of natural gas annually and is the 24th in the natural gas production worldwide [1]. Natural gas is mainly consumed by power, industry and domestic sectors as shown in Fig. 2. Since the last decade, the use of natural gas considerably increased in the transport sector. Pakistan is the second in the world, having 3.1 million vehicles consuming natural gas [2].

In fact, energy from renewable resources is the indispensable contribution. It provides energy security, decreases dependency on fossil fuels and helps in mitigation of greenhouse gases. About 10% of the worldwide primary energy supply comes from the biofuels and wastes, whereas only less than 1% from the other

* Assistant Professor, Department of Mechanical Engineering, Mehran University of Engineering & Technology, Jamshoro.
** Professor, Institute of Environmental Engineering & Management, Mehran University of Engineering & Technology, Jamshoro.
*** Assistant Professor, Department of Textile Engineering, Mehran University of Engineering & Technology, Jamshoro.

sources including geothermal, solar and wind [4]. Out of the different biofuels, the biogas could be the alternative to natural gas. Biogas is produced through the natural process of AD. AD is a biochemical process, in which several groups of microorganisms disintegrate biodegradable organic substance in hermetically sealed reactors to generate biogas and digestate (fiber and liquor). Biogas contains energy, because of the substantial presence of methane (CH_4) in it. The distinctive composition of the biogas includes 55-75% of CH_4, 30-45% carbon dioxide (CO_2), 1-2% hydrogen sulfide (H_2S), 0-1% of nitrogen (N_2) and hydrogen (H_2), and traces of carbon monoxide (CO) and Oxygen (O_2) [5]. The nutrient-rich fiber in the digestate can be employed as soil conditioner, while the liquor can serve as the liquid fertilizer. More or less, all organic substance can be processed through AD. The common organic substance take account of animal dungs, bird droppings, the organic fraction of municipal solid waste, sewage sludge; dedicated energy crops (giant miscanthus, jatropha, switch-grass, willow, poplar, canary grass, algae, and fungi); agricultural crops (maize, sorghum, Sudan grass, white clover, millet); crop residues (banana plant waste, rice straw, canola straw, sugarcane bagasse); agricultural food processing residues, organic fractions of industrial wastes and their by-products, etc.

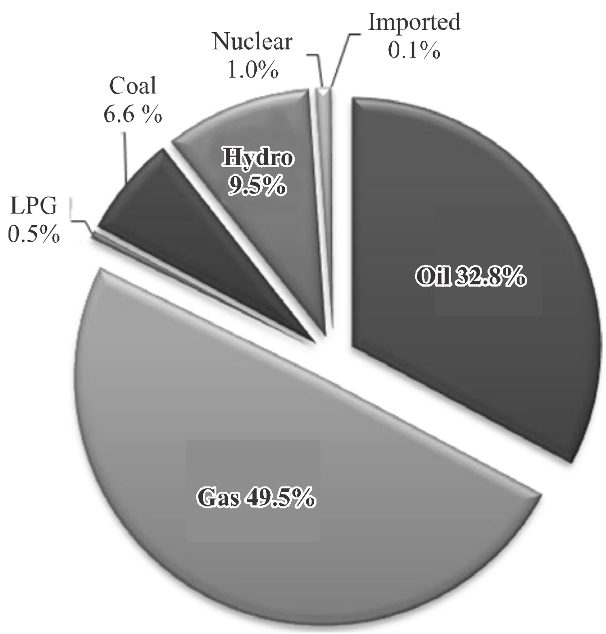

FIG. 1. PAKISTAN PRIMARY ENERGY SUPPLY 2011-2012 [3]

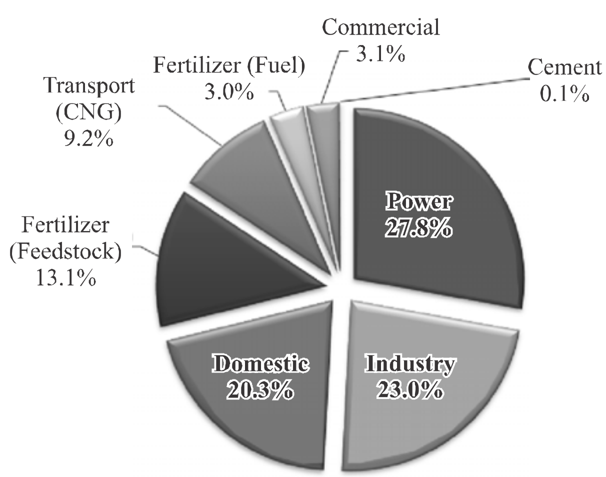

FIG. 2. PAKISTAN NATURAL GAS CONSUMPTION BY SECTOR 2011-2012 [3]

Generation of biogas from animal dung through anaerobic digestion is the most feasible way to get energy from it. Projecting the livestock census 2006, Pakistan has about 70 million heads of cattle and buffalos, and more than 90 million heads of sheep and goats. The biogas potential from these animals is about 20 thousand million cubic meters per year[7]. The dung energy from the animals can overcome the energy crisis and can fulfill the future energy demands of Pakistan.

There are more than 6000 domestic biogas plants are in operation and using buffalo and cattle dung as substrate. Based on suitable climate and numbers of livestock in Pakistan, the potential of domestic biogas plants is approximately 5 million digesters [7]. The floating drum and fixed dome are the two frequently used biogas plant types in Pakistan.During the field survey of domestic biogas plants, installed in Sindh province of Pakistan, it was observed that formaking the dung slurry, people used different ratios of dung and water. Dung to water ratio plays an important character in the AD process. The standard ratio of dung to water as given by the PCRET (Pakistan Council of Renewable Energy Technologies) guidelines is 1:1, but the higher biogas was observed through the results of the field survey in district Mirpur Khas with the higher buffalo dung to water ratios. As reported by Prakash [8] that in province Punjab, 65% of domestic biogas plants were operated by using the buffalo dung to water ratio of 1:1, while 29% were operated with more water than dung, and only 6% were operated with less water than dung. Now there as clearly two different opinions that in order to get maximum gas, either ratio 1:1 is suitable or ratio of water should be kept more than the ratio of dung.

Keeping in view the aforementioned problem, this study was carried out in order to know the most suitable ratio of buffalo dung to water ratiothat gives maximum methane production by conducting the BMP (Biochemical Methane Potential) test.

2. METHODOLOGY

2.1 Characteristics of Buffalo Dung

The Buffalo Dung was taken from the dairy farm situated nearby Mehran University of Engineering & Technology, Jamshoro, Pakistan. The TS (Total Solids), MC (Moisture Content) VS (Volatile Solids), alkalinity and pH were determined according to the Standard Methods [9]. The characteristics of buffalo dung are given in the Table 1. At the end of the BMP test, the digestate was analyzed for alkalinity, pH, and VFA (Volatile Fatty Acids) according to the Standard Methods [9]. For analyzing digestate alkalinity, pH, and VFA, samples' supernatant was used.

2.2 Inoculum

Fresh buffalo dung contains approximately 10,000 anaerobic bacteria per gram, which can only survive under strict anaerobic conditions [10]. In order to increase the methanogenic activity, an inoculum was used in this study. It was the effluent of mesophilic lab scale anaerobic digester treating buffalo dung and was working at 37± 1°C.

2.3 Preparation of Batch Reactors

The BMP test is the measure of quantity of methane that is produced as the degradation of the VS present in the dung. It involves the incubation of a small quantity of organic material along with the source of active methane producing microorganisms (methanogens) [11]. In present study, 500mL glass reactor bottles were used and the effective volume of each reactor was kept as 250mL. Each reactor bottle was filled up to 200mL with different ratios of buffalo dung and water as given in the Table 2. Six ratios were made based on the weight of fresh buffalo dung to water i.e. 2.0, 1.0, 0.67, 0.5, 0.4 and 0.33 consisting of 9.4, 7.1, 5.7, 4.8, 4.0 and 3.6% of the TS. To obtain statistical significance, each ratio was tested in duplicate batch experiments. In addition to buffalo dung and water, a 500mg of sodium hydrogen carbonate ($NaHCO_3$) was supplemented in each reactor bottle, which increases the buffer capacity of the slurry. Also, a 50mL of inoculum was added in each reactor bottle. The water bath was set to the mesophilic temperature of 37± 1°C. The reactors were then connected to the CO_2 absorption bottles, which were filled with the mixed solution of NaOH and Thymolphthalein. In order to achieve the anaerobic condition in the reactor bottles, each of them was purged

TABLE 1. CHARACTERISTICS OF BUFFALO DUNG

TS (%)	VS (% TS)	pH (mg $CaCO_3$/L)	Alkalinity (mg CH_3COOH/L)	VFA
14.21	89.27	6.90	1317	720

with nitrogen gas for two minutes. Finally, all reactor mixing motors were connected in parallel with each other and to the control panel. The mixing motor running time was set to two minutes, while the off time was set to ten minutes.

2.4 Loss of Volatile Solids

The percentage VS loss was calculated by using Equation (1), where VS_{out} and VS_{in} are the percentages of VS at the end and start of the BMP test respectively.

$$VS_{loss} = \left(1 - \frac{VS_{out}}{VS_{in}}\right) \times 100 \quad (1)$$

3. RESULTS AND DISCUSSION

In present study, BMP test was used to scrutinize the effect of substrate to water ratio on production of methane from buffalo dung. The BMP test waste reminated after incubating samples for 51 days. The pH, alkalinity and VFA are the core parameters, in identification of inhibition of the AD reactor [12-13]. In order to overcome the inhibition within the batch rectors, a small quantity of sodium hydroxide (NaOH) was added. The digestate of each rector was investigated for pH, alkalinity and VFA and the results are given in the Table 3. All the batch reactors were within the stable range of pH i.e. 6.8-7.2 [14], except for the buffalo dung to water ratio 1.0 that is slightly higher and has pH value of 7.3. On the contrary, because of the prolonged time of incubation, the batch reactors have low alkalinity and higher values of VFA. However, for the buffalo dung to water ratio of 2.0 and 1.0 the ratio of VFA to alkalinity was near the stability [15]. The other ratios were unstable, which is in accordance to the findings of Baserja [16] that AD of dung in unstable below a TS content of 7%.

The cumulative methane production from the different buffalo dung to the water ratios as obtained from the each reactor along with the error bar is illustrated in Fig. 3. The maximum methane production was observed as 2788NmL from buffalo dung to the water ratio of 2.0, followed by 2009, 1525, 1262, 1009 and 922 from the ratios of 1.0, 0.67, 0.5, 0.4 and 0.33 respectively. Thus it establishes that in AD, decreasing the buffalo dung to water ratio from 2.0-0.33 decreases the quantity of methane in a linear way with R^2 (coefficient of determination) of 0.96.

TABLE 3. THE RESULTS OF DIGESTATE ANALYSIS AT THE END OF BMP TEST OF DIFFERENT BUFFALO DUNG TO WATER RATIOS

Buffalo Dung to Water Ratio (g/g)	pH	Alkalinity (mg $CaCO_3$/L)	VFA (mg CH_3COOH/L)	VFA/ Alkalinity
2.00	7.1	1067	600	0.56
1.00	7.3	867	600	0.69
0.67	7.0	767	600	0.78
0.50	7.1	700	600	0.86
0.40	7.0	650	800	1.23
0.33	7.2	600	400	0.67

TABLE 2. THE RESULT OF METHANE PRODUCTION FROM DIFFERENT RATIOS OF BUFFALO DUNG AND WATER

Buffalo Dung to Water Ratio (g/g)	Buffalo Dung (g)	Water Reactor (g)	TS (%)	CH_4 (NmL/gVS_{loss})	VS_{in} (g)	VS_{out} (g)	VS_{loss} (%)
2.00	133	67	9.4	226.4	16.87	4.6	75.9
1.00	100	100	7.1	198.6	12.68	2.6	81.9
0.67	80	120	5.7	180.8	10.15	1.7	84.9
0.50	66	134	4.8	174.0	8.50	1.2	86.9
0.40	57	143	4.0	159.2	7.23	0.9	89.0
0.33	50	150	3.6	164.2	6.34	0.7	89.8

The results of the production of methane in terms of VS_{loss}, the weight of VS (at the start and end) and percentage loss of VS are given in Table 2. The highest methane production of 226.4NmL/gVS_{loss} was observed from buffalo dung towater ratio of 2.0, followed by 198.6, 180.8, 174.0, 164.2 and159.2NmL/gVS_{loss} form buffalodung tothe water ratio of 1.0, 0.67, 0.5, 0.33 and 0.4 respectively. Thus buffalo dung to the water ratio of 2.0 is the most appropriate to get the maximum methane production. This result is in agreement with the Sadaka and Engler [17] that among the various parameters, water content is also a significant parameter, which affects the AD of solid wastes.

Flow rates of methane from all the six ratios is shown in Fig. 4. Methane production was started from day one. The methane production starts decreasing considerably after 19th day of the incubation due to the decrease of the major portion of the biodegradable organic matter. Before the methane production terminated, first it exhibits two crests approximately started at the second day and ninth day respectively. Afterwards, its flow rate decreases almost linearly. This fluctuation of the methane flow rate is due to the dynamic balance between the acidogenic and the methanogenic phase of an AD process [18]. At an average the second crest was ended at 20 days, which can be considered as the appropriate hydraulic retention time, if the digestion is carried out in the continuous reactor. Moreover, the highest biogas production rate was observed on the fifth day.

Specific methane production on the basis of loss of VS, TS in the reactorand the loss of VS are represented in Fig. 5. It was observed that as the mass of the TS increases from 3.6-9.4%, the specific methane potential also increases. According to Igoni, et. al. [19] as the TS concentration of the municipal solid waste increased from 4-10% the methane production also increases.The result of the present study is in correspondence to the literature that the higher methane production from the dung could be obtained at the TS content between 7-9.2% [20-21]. On the contrary, as the mass of the solids decreases from 9.4-3.6%, the loss of VS increases. This reveals that higher

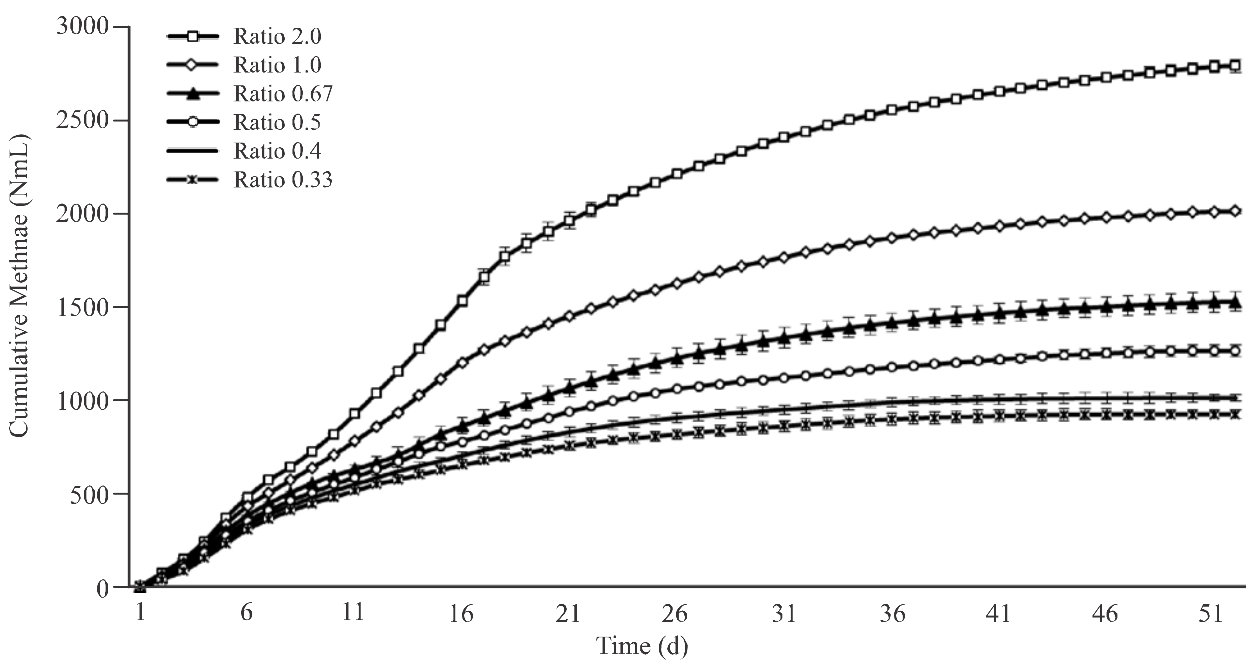

FIG. 3. THE CUMULATIVE METHANE PRODUCTION FROM THE DIFFERENT BUFFALO DUNG TO THE WATER RATIOS

methane production could be achieved at the TS concentration of 9.4%, while higher VS destruction could be achieved at the TS concentration of 3.6%. Itodo and Awulu [22] stated that the quantity of biogas produced at the higher TS concentrations is low as compared to lower TS concentrations because of the former one is more acidic. Moreover, in case of lower TS concentrations the level of microbial activity is also low because of the larger amount of the water [19].

The law of conservation of mass, states that for any system closed to all types of transforms of matter and energy, the mass of the system must remain constant over the time, while it may be rearranged in space. Certainly, if the mass balance of the batch reactor is carried out, it shows that the VS added in the batch reactor either produces the biogas or remained in the digestate. Besides, the higher destruction of the VS produces more quantity of the biogas. The more production of biogas does not mean that more

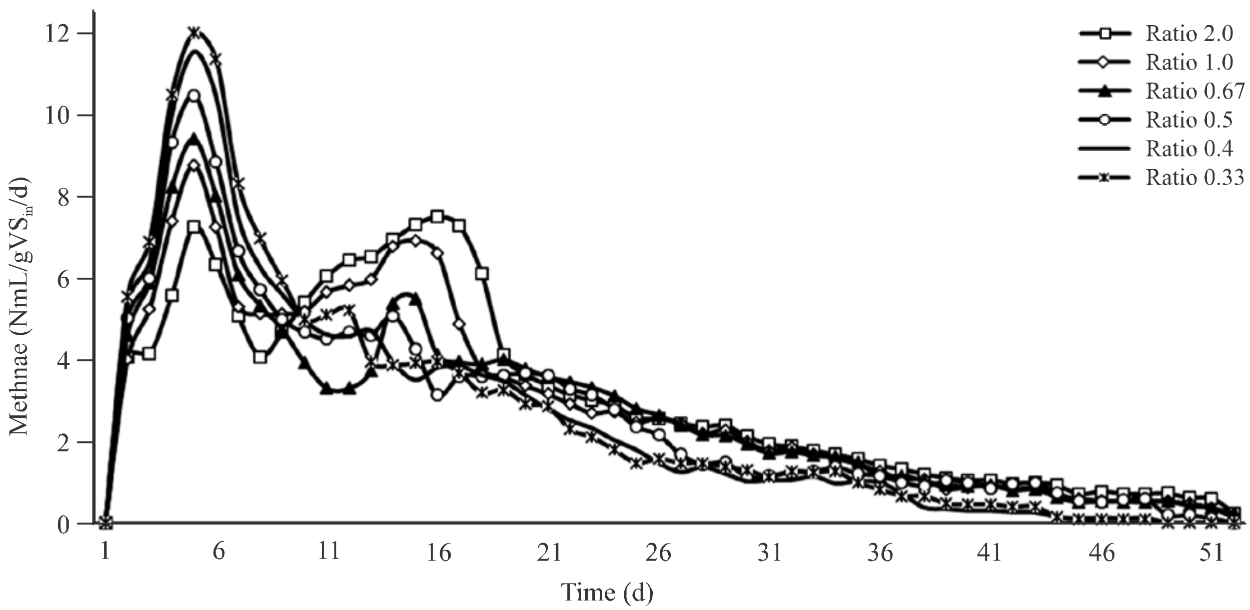

FIG. 4. THE METHANE FLOW RATE FROM THE DIFFERENT BUFFALO DUNG TO THE WATER RATIOS

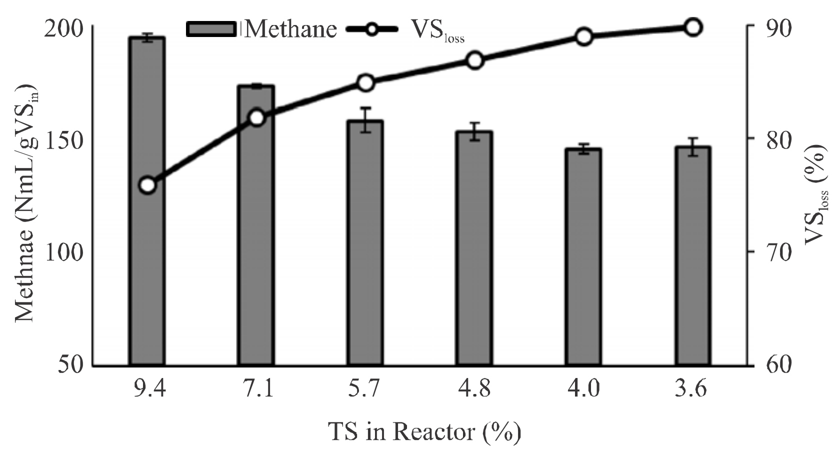

FIG. 5. SPECIFIC METHANE PRODUCTION, PERCENTAGE TS IN REACTOR AND VS LOSS FROM THE DIFFERENT RATIOS OF BUFFALO DUNG AND WATER

quantity of the methane has been produced. Considering the results of the present study, the reactors with the low concentration of solids produces low quantity of the methane but the VS destruction is higher. This means that at low solids concentration more quantity of biogas was formed and that contains more quantity of the CO_2. On the contrary, the quality of the methane produced from the low solid reactors is less than the quality of the methane produced from the high solid reactors. Salminen and Rintala [23] have reported the similar results that at the VS_{loss} of 76%, the methane yield was 0.52m^3/kgVS_{in}, while at VS_{loss} of 74%, the methane yield was 0.55 m^3/kgVS_{in}.

Moreover, use of low solids in anaerobic digester, which do not have any substrate mixing mechanism e.g. floating drum or fixed dome type digester, results in settling of a solid particle at the bottom of the reactor. This settlement of the solids creates a dead volume and reduces the effective volume of digester, which ultimately result in the decrease of methane production. Quite the reverse, use of high solids in anaerobic digester at long run results the formation of a thick layer in inlet and exit port, which obstruct the substrate and digestate flow. Thus, for producing methane from the digestion of buffalo dung taking the buffalo dung to water ratios of 2.0, horizontal digesters are recommended that can handle the high concentration of solids. However, for floating drum or fixed dome digesters the buffalo dung to water ratio of 1.0 is the most appropriate.

The present study focuses on the most suitable buffalo dung to water ratio that gives maximum methane gas production but not the maximum biogas production. Biogas is the mixture of methane, carbon dioxide and traces of other gases. Present study yield that the maximum methane can be produced if water to dung ratio is kept as 2.0, which is clearly not the same result as the PCRET states. On the contrary, as the floating drum type biogas plant cannot handle the dung to water ratio of 2.0 (high solids), thus for only floating drum type and fixed dome type biogas plants the water to dung ratio of 1.0 is suitable. But if the biogas plantso designed, which has capability to handle the high solids then the water to dung ratio of 2.0 is recommended.

Moreover, the statement of the fixed dome and floating drum biogas plants' operators is also correct that the increasing the quantity of water increases the biogas. Present study also reveals that at lower solid content (high quantity of water), percentage of VS destruction is more and the quantity of biogas (mixture of methane and carbon dioxide) produced is also high but actually produces less quantity of methane gas.

4. CONCLUSION

Present study reveals that the AD of the buffalo dung yields highest methane production of 226.4 NmL/gVS_{loss} at buffalo dung tothe water ratio of 2.0; followed by 198.6 NmL/gVS_{loss} at buffalo dung tothe water ratio of 1.0. Correspondingly, decreasing the buffalo dung to water ratio from 2.0-0.33 decreases the quantity of methane in a linear way with R^2 of 0.96. For producing methane from the digestion of buffalo dung taking the buffalo dung to the water ratios of 2.0, horizontal digesters are recommended that can handle the high concentration of solids. However, for floating drum or fixed dome digesters the buffalo dung to the water ratio of 1.0 is the most appropriate. The suitable hydraulic retention time of the anaerobic digester treating buffalo dung was observed as 20 days. Moreover, it was also observed that as the mass of the total solids increases from 3.6-9.4%, the specific methane potential also increases, while the loss of VS decreases. Thisexposes that higher methane production could be achieved at the total solids content of 9.4%, while higher VS destruction could be achieved at the TS content of 3.6%.

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