Field Studies of Biogas Digester with Partitioned Walls

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ABSTRACT

In the present investigation, field experiments were carried out to investigate the effect of partitioned walls as well as temperature on the performance of biogas digesters. Two fixed dome type of Deenbandhu model biogas digesters, one without and one with partitioned walls, were installed, and their performance was evaluated on the basis of gas production during the winter months from 1st November 2003 to 29th February 2004. Cowdung-water mixture with a total solid (TS) concentration of 8% was fed in each digester of 1 m^3/day capacity. Both the digesters under investigation were continuous type, and fed with slurry from the same raw material at the ambient temperature. Test results were also conducted on a digester of 3 m^3/day capacity without walls to compare the performance of the above two digesters.

1. INTRODUCTION

Development of biogas technology in India began more than half a century ago. About 2.7 million domestic biogas plants have been constructed in the whole country [1-3]. Despite the increasing popularity and acceptance of the promising renewable energy technology, the two basic designs, viz., the KVIC (Khadi Village Industries Commission) model (floating dome plant with a cylindrical digester) and Janata model (fixed dome plant with a brick reinforced moulded dome) digesters remain, by and large, beyond the reach of most rural households. However, as per the recommendation of the Action for Food Production (AFPRO), a cheaper version, named as Deenbandhu model, was developed in 1982. This model with a hydraulic retention time (HRT) of 55 days was found to be 30-45 % less expensive than the above two models [4]. Basically, the Deenbandhu model is a fixed dome type biogas plant, and it has gained wide popularity in India [4-6]. Kalia and Kanwar [7] suggested that most digesters in the Himachal Pradesh of India operate under the lower mesophilic range (16±24°C) for nearly eight months from March to October and in a psychrophilic range (13±15°C) for rest of the year. However, for maximum biogas production the temperature value must fall in the mesophilic range (30 to 38^{0}C) since, temperature is an important factor in removal of pathogenic organisms in an anaerobic digester [8]. In 1994, Konwar et al. [9] developed a modified Deenbandhu biogas plant and evaluated the performance under hilly conditions, i.e., in Himachal Pradesh of India. However, literature on modification of the Deenbandhu biogas plant for the plain region, e.g., for the northeastern region of India, is scarce. In this region, the ambient temperature falls in the range of 26^{0}C to 35^{0}C for a period of nearly eight months; and for the remaining period it falls in the range of 15^{0}C to 25^{0}C.

The overall performance of a digester usually depends upon several key parameters, viz., temperature, C/N ratio, agitation and pH value [2-5]. The effect of temperature was studied by means of internal heating, and was observed that gas production is maximum in the mesophylic temperature range [10]. Besides temperature, agitation was also found to play a significant role in the production of biogas [12, 13]. Studies conducted by various researchers [1-2, 4] indicate that higher ambient temperature results in higher gas production. The digesters installed in the northeastern part of India ($25^{0}06^{/}$N, $91^{0}35^{/}$ E) seem to have shown a poor performance in winter months because of lower ambient temperature. This is also probably due to incomplete digestion of the input material caused by lesser retention time [12]. Thus, there is a need to design and develop efficient digester systems with higher retention time. The partitioned walls, inside the digester, seem to be an attractive proposition to improve the sequential flow and ensure to have even retention time for old and new slurry feeds and thereby yielding more biogas in the winter months.

In the present study, two Deenbandhu models, one without and one with partitioned walls, have been considered to assess their performances in terms of the gas production rate. In view of this, two digesters each with $1m^3$ capacity without and with partitioned walls were installed, and their performance was evaluated during the winter months from 1st November 2003 to 29th February_2004. Henceforth, these digesters will be designated as the Digester-I and Digester-II, respectively, in the description. For each of the digesters, cowdung-water mixture with total solid (TS) concentration of 8% was used as the feed. The monthly average pH value in each case was also monitored. In order to compare their performances, experiments were also conducted on a similar type of digester of 3-m^3 capacity without partitioned wall (designated as the Digester-III).

2. MATERIALS AND METHODS

The installation of the digesters without and with partitioned walls is shown in Figure 1. The spherical dome of the digester without wall is kept above the ground level. The digester with the partitioned walls is constructed just below the ground level (Figure 1). The digesters are located horizontally at a distance of 450 cm from each other as seen in Figure 1. For the partitioned case, both the walls are at a distance of 47 cm from the center. Thus, there is gap of 94 cm between the two walls. As seen from Figure1, the height of the wall near the inlet is slightly more (70 cm) than the height of the wall

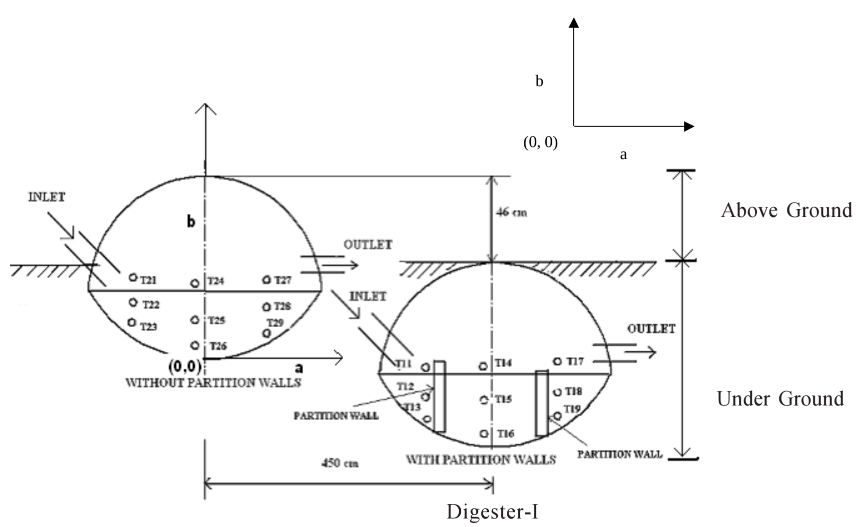

Fig.1. Developed biogas digesters without and with partitioned walls (a and b denote the horizontal distance and vertical distances from the bottom of the digester respectively)

near the outlet (60 cm). This is provided to maintain a good environment for the microbial growth. These digesters were continuous type and fed with cowdung-water mixture with the total solid (TS) concentration of 8%. The C/N ratio of cowdung in each case was 25.6. The loading rate for the Digesters-I and II was maintained at 58 kg/day (consisting of 29 kg of cow dung with 29 kg water). The input slurry were prepared and fed into the digesters from the same raw material and at ambient temperature. The variation of the digester temperature and the ambient temperature has also been investigated to find their effect on the biogas production rate. The locations of the thermocouples meant for the temperature measurement have also been shown in Figure 1 (denoted by T). The detailed dimensions of the 1m3/day digester are schematically shown in Figure 2.

Each of the digesters has been connected to a computer based data acquisition system to record the digester temperature. In each case, nine thermocouples were inserted at different locations as shown in Figure 1. Three were located near the tank inlet, three at the center and the remaining three at the outlet of the tank. The position of a thermocouple sensor in a particular digester is indicated by the symbol TXY (a, b), where T denotes temperature, X the particular digester, Y the thermocouple number and (a, b) denote the horizontal and vertical distances from the bottom of the digester, respectively (Figure 1). All the thermocouple positions are shown in Table 1. Alkality and acidity of the solutions (i.e., pH value) were measured with help of a digital pH meter.

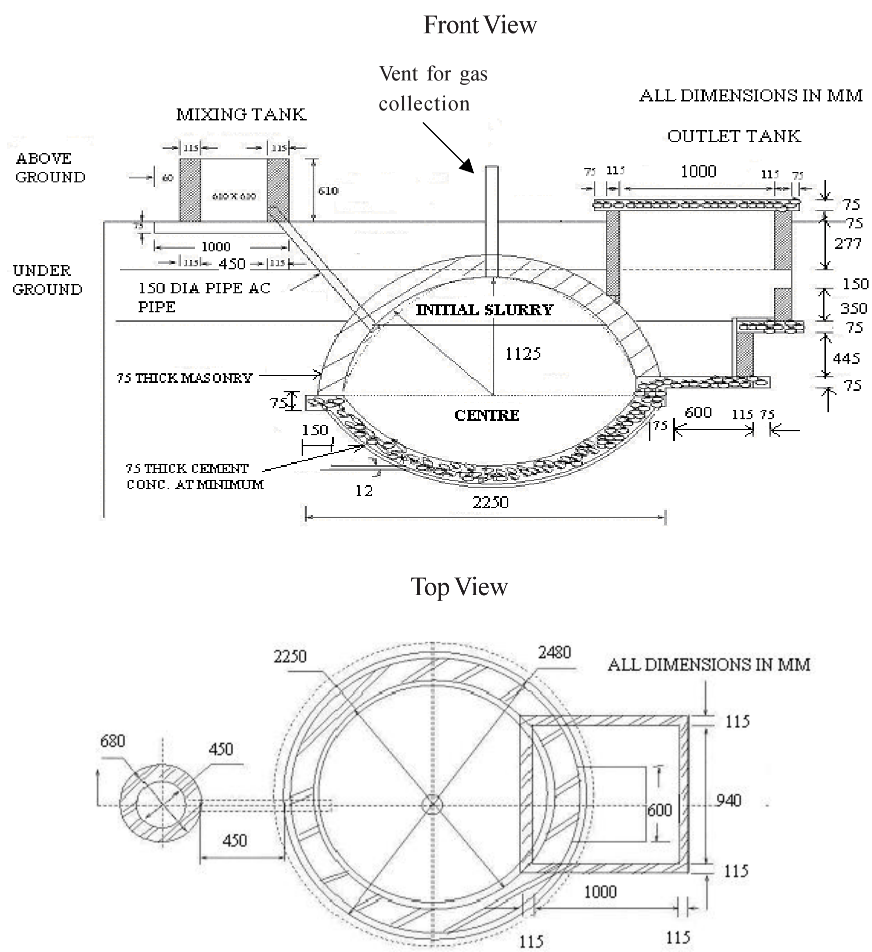

Fig. 2. Schematic diagram of a 1 m^3/day deenbandhu model (Digester-II)

Table 1. Thermocouple Position for the Tested Digesters

Thermocouple Number	Thermocouple Position					
	Digester-I	Temperature (average) ^{0}C	Digester -II	Temperature (average) ^{0}C	Digester -III	Temperature (average) ^{0}C
1	T11 (66, 74)	22.0	T21 (90, 27)	25.3	T31 (46, 107)	25.6
2	T12 (47, 84)	22.0	T22 (19, 15)	24.5	T32 (79, 106)	26.5
3	T13 (28, 78)	23.4	T23 (60, 60)	19.6	T33 (8, 80)	26.7
4	T14 (27, 5)	24.4	T24 (101, 60)	19.7	T34 (13, 105)	25.6
5	T15 (50, 17)	23.5	T25 (98, 82)	21.0	T35 (70, 78)	26.5
6	T16 (100, 28)	24.0	T26 (38, 76)	22.0	T36 (109, 78)	22.6
7	T17 (85, 74)	25.1	T27 (96, 52)	24.3	T37 (117, 97)	26.0
8	T18 (33, 18)	24.8	T28 (32, 43)	25.4	T38 (94, 111)	23.0
9	T19 (60, 23)	24.5	T29 (78, 85)	24.7	T39 (16, 90)	17.6

3. RESULTS AND DISCUSSION

The gas production rates on the daily basis for the two digesters without and with partitioned walls are shown in Figures. 3 to 6. These data are taken over a four-month period from November 2003 to February 2004. In these figures, the data for a 3 m^3/day digester are also shown to compare the performance of 1 m^3/day digester without and with partitioned walls. Figure 3 shows the gas production during the month of November 2003. From Figure 3, it is seen that daily gas production curves for the test cases are similar in trend showing frequent peaks. However, daily gas production is less for the digester without partitioned walls compared to the digester with partitioned walls. As observed from Table 2, the cumulative gas production for Digester-I was 2.1 times that of the Digester-II, while Digester-III shows 137.30 kilolitres of gas production amounting a surplus of 27 kilolitres only as compared to the Digester-I. The measured pH value at the time of feeding was 6.68 for all cases. However, the average outlet pH values for this month were found to be 7.43, 7.58 and 7.62 for Digester-I, Digester-II and Digester-III, respectively.

The daily gas production curves for December-2003 are similar to that for November-2003 (Figure 4). However, the cumulative gas production for the Digester-I was 1.84 times that of the Digester-II (Table 2). Further, it is seen that the monthly gas production of the Digester-I is higher as compared to other two cases. The outlet pH values in this case were found to be 8.03, 7.86 and 8.1 for Digester-I, Digester-II and Digester-III, respectively.

During January 2004, the cumulative gas production in Digester-I was 2.07 times that of the Digester-II. As compared to Digester-III, it shows a higher rate by 1.11 times. The outlet pH values recorded were 8.0, 7.9 and 8.13 for the Digesters-I, II and III, respectively (Table 2). Comparison of the daily gas productions for the digesters in this month is shown in Figure 5. Observations show that the gas productions for the Digester-I and Digester-II are almost similar, and therefore, the curves overlap with each other. However, the gas production curve for the Digester-III falls far below the curves of the Digesters-I and II.

Finally, in February 2004, the cumulative gas production in Digester-I was 2.14 times that of the Digester-II. However, as compared to the Digester-III, it shows a lesser gas production by 4.32 kilolitres. The average pH values were found to be 7.64, 7.53 and 7.7 for Digesters-I, II and III, respectively (Table

2). Daily gas production variation in this month is shown in Figure 6, and shows a similar trend as that of January-2004 (Figure 5).

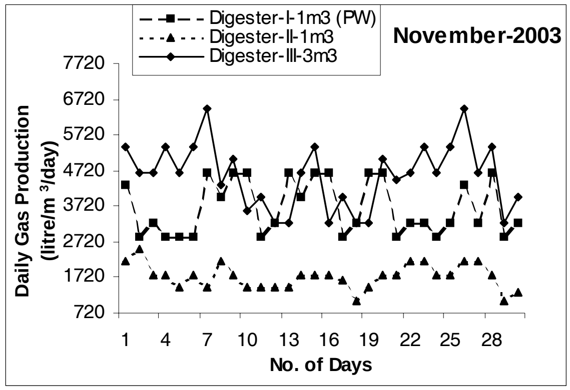

Fig. 3. Variation of gas production for November-2003 (PW denotes partition walls)

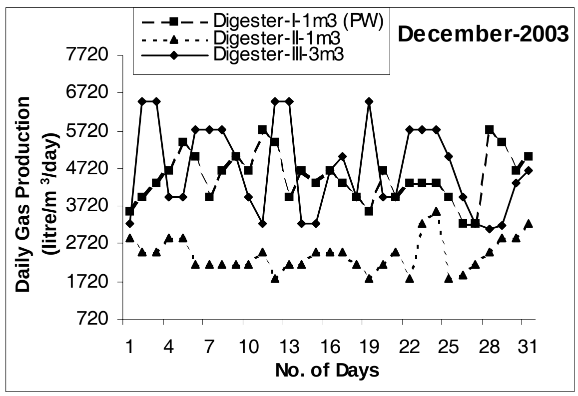

Fig. 4. Variation of gas production for December 2003

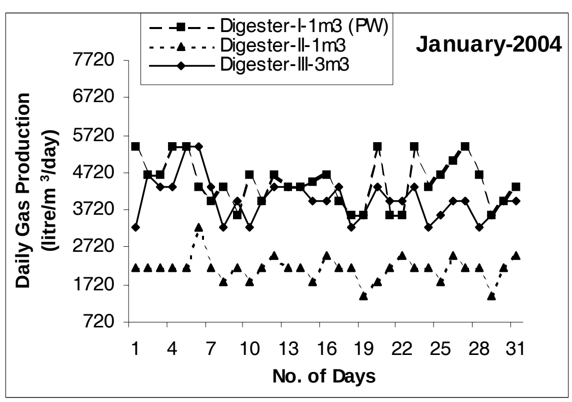

Fig. 5. Variation of gas production for January 2004

From the above discussion, it has been observed that the gas production rates show similar trend along the entire period considered. However, the production rate is higher in the case of Digester-

I (with 1 m^3/day capacity having partitioned walls). It has been noticed that the gas yield value in the Digester-I is approximately equivalent to Digester-III (3 m^3/day capacity). Comparatively, Digester-II produces a lower amount of gas during the tested period. This means that the use of the partitioned walls in the Digester-I has a significant effect in controlling the temperature variation inside the digester, thereby yielding large gas throughout the period. This can further be justified from the study of temperature variation inside the digesters as shown in Figures 7 and 8.

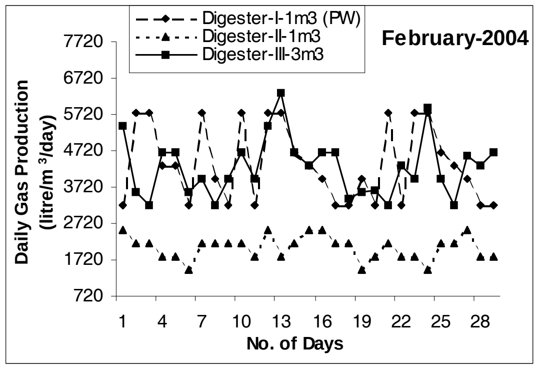

Fig. 6. Variation of gas production for February 2004

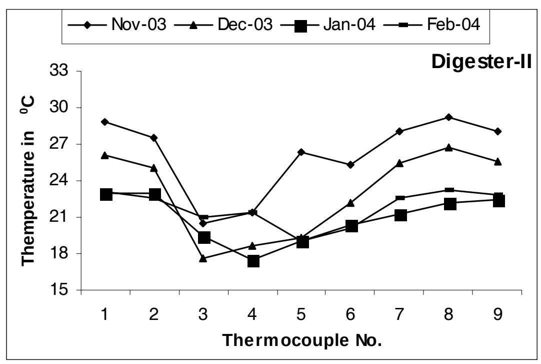

Fig. 7. Variation of temperature for digester-II

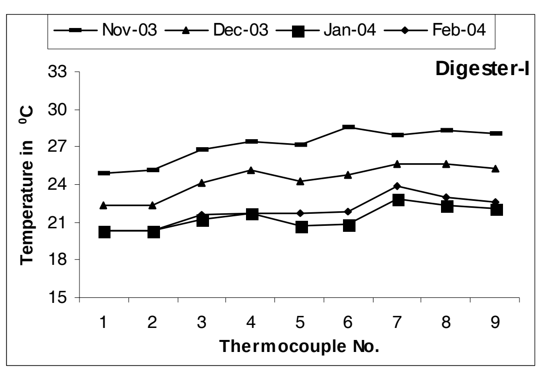

Fig. 8. Variation of Temperature for Digester-I

Table 2. Comparison of Cumulative Gas Production and pH Value

Digester	November-2003		December-2003		January-2004		February-2004	
	Gas production in kilolitres	Outlet pH Value	Gas production in kilolitres	Outlet pH Value	Gas production in kilolitres	Outlet pH Value	Gas production in kilolitres	Outlet pH Value
Digester-I	110.52	7.43	138.96	8.03	138.24	8.00	126.72	7.64
Digester-II	52.27	7.58	75.31	7.86	66.60	7.90	59.04	7.53
Digester-III	137.30	7.62	126.36	8.10	124.20	8.13	131.04	7.70

Figures7 and 8 depict the weekly variation of the digester temperatures from 1st November 2003 to 29th February 2004. It is seen that the variation of the temperature for the Digester-I is small as compared to the Digester-II. The local temperature variation curves in the Digester-I (partitioned wall case) and the Digester-II (without partitioned wall case) are also different. In case of the Digester-I, the temperature curves almost uniformly show small temperature variation from inlet to outlet. This uniform temperature is advantageous for the microbial growth as well as microbial activity, and hence, yields a large gas production. This is because the microorganisms can work comfortably in lower thermal stress condition due to small temperature variations. A large variation of temperature within the digester is undesirable [12]. A maximum temperature of 28.6^{0}C was observed in November 2003, while January 2004 showed a minimum temperature of 20.5^{0}C. The average monthly variation of temperature in the Digester-I was found to be 3.3^{0}C. Digester-II shows a large variation of temperature as compared to the Digester-I. In this case also, the temperature curves are not uniform and the temperature varies from the inlet to outlet of the digester. A maximum temperature of 28.8^{0}C was observed in November 2003, while a minimum temperature of 17.5^{0}C was recorded in January 2004. This high variation of temperature has caused a low gas production. It has been suggested that to increase the biogas production rate, the variation of temperature must be reduced, as microbial growth cannot sustain in such a situation [12]. The average monthly variation of temperature in this case is found to be 6.8^{0}C.

The weekly variation of ambient temperature for the entire period is shown in Figure 9 and the monthly variation of ambient temperature, digester temperature and biogas production rate for the said period are shown in Figures 10 and 11. In November 2003, the maximum variation of temperature is of the order of 5^{0}C, whereas it is less than 1^{0}C in December 2003 (Figure 9). When this temperature variation is compared with the gas production (Table 2, Figures 10 and 11), it has been realized that both Digesters-I and II show a lower gas production in November-2003 as the temperature drops significantly in this month as observed in Figure 9. However, the variation of atmospheric temperature is minimal in the month of December 2003, and as such, the gas production is high in December 2003. It can be interpreted from above that for maximum gas production, the temperature variation inside the digester should be minimum, and this can be achieved by providing partitioned walls inside the digester. Furthermore, the biogas production rate is also influenced significantly by the ambient temperature.

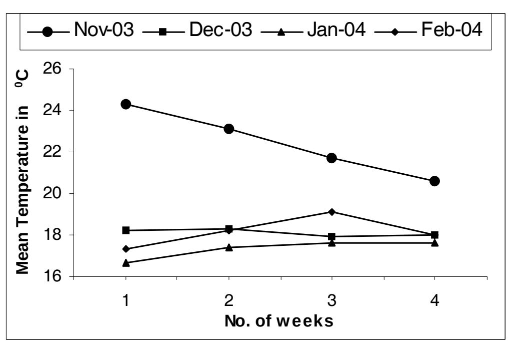

Fig. 9. Variation of Ambient Temperature

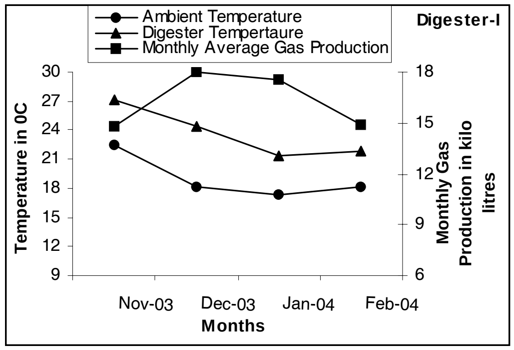

Fig. 10. Monthly variation of ambient temperature, digester temperature and gas production

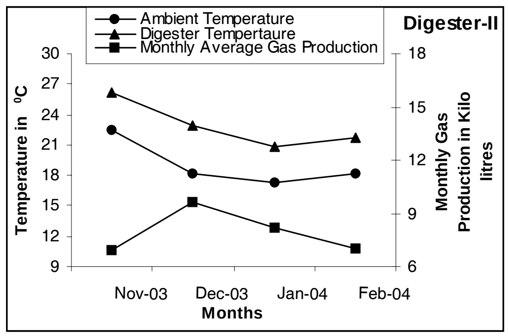

Fig. 11. Monthly variation of ambient temperature, digester temperature and gas production

In the present investigation, it was found that in the case of the partitioned wall digester, the temperature variations within the digester are small, and therefore, the microorganisms can sustain, develop and multiply under lower temperature stress condition. As a result, biogas production rate improved significantly. The operational retention time of the modified digester was found to be 59.1 days, which is an important parameter for a particular region. It is expected that this modified digester will work well in the winter months as well in the other regions, where the ambient temperature falls below 17^0C.

4. CONCLUSIONS

The overall process of anaerobic digestion occurs through the symbiotic action of a complex consortium of bacteria. For the efficient performance of a biogas plant, it is therefore necessary to regulate the factors that affect the bacterial activity. Temperature and pH of digester contents are to be maintained within the desired range. Similarly, loading rate of the feedstock and the withdrawal rate of the digester slurry should also be properly balanced and continuously monitored. In the present investigation, the effect of the partitioned walls, digester temperature and ambient temperature on the biogas production rates were studied. Two fixed dome type of Deenbandhu model biogas digesters each with 1 m^3/day capacity, one without and one with partitioned walls, were installed, and their performance was evaluated. Results of these two digesters were compared with a similar type of digester with a capacity of 3 m^3/day and without partitioned walls. From the present study, it can be concluded that the gas production is maximum for Digester-I (with partitioned walls) as compared to Digester-II (without partitioned walls). Digester-III with 3 m^3/day capacity, on the other hand, shows a similar gas production as that of Digester-I. The present study directly shows that the digester temperature and the ambient temperature affect the biogas production rate significantly. The operational retention time in case of partitioned wall digester is found to be 59.1 days, which is 4.1 days more than that of existing Deenbandhu model. This helps to achieve a complete digestion of the input material. Usually, in the winter season, the ambient temperature falls below 15^0C, and therefore, it takes a longer time period for complete digestion. The present investigation proposes an efficient design of the existing digester with partitioned walls in terms of savings of space, materials and overall cost.

5. ACKNOWLEDGEMENT

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