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Short communication

Reduced hydraulic retention times in low-cost tubular digesters: Two issues

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ABSTRACT

Low-cost tubular digesters have been implemented in several developing countries. One of the problems reported from field surveys is that biogas generation that does not meet the user's expectations. This report provides two reasons for the discrepancy between the biogas generation rate estimated in the design phase and the actual rate measured after construction, due to a lower final hydraulic retention time (HRT). The hydraulic retention time is normally determined from the liquid volume calculated from the cylindrical shape of the bag and not from the trench dimensions. The result is a reduction in HRT of 6%–51%, depending on the dimensions of the trench recommended by various authors. Another factor that is not normally considered is the influence of the biogas pressure on the liquid level inside the digester which negatively affects the liquid volume of the digester, reducing HRT by as much as 15%.

1. Introduction

Low-cost digesters are characterized by the absence of active mixing devices and/or active heating systems. As a consequence they do not need sophisticated monitoring either. They are made from locally available materials, usually plastic bags for the main tank and PVC pipes to carry the biogas. This technology works, with suitable adaptation, in tropical, continental, and cold climates.

Low-cost digesters have been implemented in developing countries since the 1980s. Due to their simple design, and construction from readily available materials, they can be classified as appropriate technology. The "red mud PVC" bag designed in Taiwan by Pound in 1981 [1] was the seed for the technical development of this continuous-flow flexible tube digester. Further development was conducted mainly by Preston in Ethiopia, Botero in Colombia [2] in 1987, and Bui Xuan An in Vietnam [3] in 1994. In all cases the digesters were built for use in tropical climates. Martí-Herrero, in the *altiplano* of Bolivia in 2003, adapted Botero's design to cold climates adding a greenhouse with high thermal mass, insulation material and increasing the size of the digester [4,5].

The technology has been promoted in several developing countries such as Colombia, Ethiopia, Tanzania, Vietnam, Cambodia, China, Costa Rica, Bolivia, Peru, Ecuador, Argentina, Chile, Mexico, etc [2,4,6–10].

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Table 1 – Analysis of the dimensions of the trenches from different authors and circumferences.

Author	C (m)	r (m)	a (m)	b (m)	p (m)	L_{bell} (m)	L_{bell}/b	CS_{trench} (m^2)	CS_{tub} (m^2)	$\%V_{liq}$	$CS_{trench}/CS_{tubular\_liq}$
Martí-Herrero, 2008 [5]	2.5	0.40	0.4	0.6	0.7	0.69	1.14	0.35	0.50	75	0.94
Rodriguez et al., 1999 [10]	2.5	0.40	0.7	0.9	0.9	0.002	0.00	0.72	0.50	80	1.79
Sarwatt et al., 1995 [8]	2.5	0.40	0.5	0.65	0.8	0.41	0.63	0.46	0.50	80	1.14
Martí-Herrero, 2008 [5]	3	0.48	0.5	0.7	0.8	0.89	1.27	0.48	0.72	75	0.89
Aguilar, 2001 [13]	3	0.48	0.65	0.85	0.85	0.64	0.75	0.64	0.72	75	1.19
Martí-Herrero, 2008 [5]	3.5	0.56	0.6	0.8	0.9	1.09	1.36	0.63	0.97	75	0.86
Bui Xuan An et al., 1997 [11]	3.9	0.63	0.8	1.2	1	1.09	0.91	1	1.23	80	1.02
Poggio, 2009 [12]	4	0.64	1	1.6	1	0.90	0.56	1.3	1.27	80	1.28
Martí-Herrero, 2008 [5]	4	0.64	0.7	0.9	1	1.29	1.43	0.8	1.27	75	0.84
Botero et al., 1987 [2]	4	0.64	0.64	0.7	0.7	1.96	2.80	0.469	1.27	75	0.49

One of the problems reported from field surveys of this type of digester is that end-users complain that daily biogas yields are less than those indicated by the designers.

This paper reports two common scenarios that engage the calculation of hydraulic retention time (HRT) for a low-cost tubular digester. The first scenario deals with the way these digesters are designed, using the theoretical tubular volume of the plastic bag instead of the real liquid volume of its containing trench. The second scenario deals with the gas pressure reached in these digesters which decreases the liquid volume due to the expansion of the gas.

2. Loss of HRT by the typical, but incorrect, design method

Generally, a low-cost tubular digester is dimensioned using the cylindrical volume formed by the tubular plastic. This volume is separated into two phases—liquid and gas. Depending on the author the liquid volume is reported as 80% of total cylindrical volume [8–12] or 75% [2,5,13]. The liquid volume is supposed to fill the volume of the trench in which the digester is situated. In order to obtain the total volume, the cross section of the cylinder is multiplied by the length of the digester, assuming that this volume will remain unchanged after the digester is placed in the trench. The dimensions of the trench are given in each case as 'recommended', but no methodology or justification is provided.

The correlation between the real final liquid volume (determined by the trench), and the theoretical liquid volume (determined as 75–80% of the total cylindrical volume), do not coincide as shown in Table 1. Table 1 shows data from the most popular publications that specify dimensions for the trench. The parameters relate to Fig. 1.

Table 1 shows the circumference of the plastic employed (C); the radius of the tube (r); dimensions of the trench (a, b, and p); the length of the biogas bell (L_{bell}) that corresponds with the length of plastic that remains after the walls of the trench are covered; the cross sectional area of the trench (CS_{trench}); The cross sectional area of the cylinder associated with the plastic utilized ($CS_{tubular}$); the % of the liquid volume of the cylinder assigned by the authors ($\%V_{liq}$); The ratio $CS_{trench}/CS_{tubular\_liq}$, where $CS_{tubular\_liq} = CS_{tubular} \times \%V_{liq}$; and the relationship between the length of the biogas bell (L_{bell}) and the upper width of the trench (b).

The main parameters for the analysis are L_{bell}/b and $CS_{trench}/CS_{tubular\_liq}$.

The ratio L_{bell}/b should be greater than 1 in order to form the biogas bell. If $L_{bell}/b < 1$, the design dimensions are incoherent as the plastic circumference cannot cover the perimeter of the trapezoidal trench. Of the dimensions studied (see Table 1), only those proposed by Botero [2] and Martí-Herrero [5] have $L_{bell}/b > 1$. Only by fulfilling this condition can the level of the liquid completely fill the trench and leave enough plastic to form the biogas bell.

The ratio $CS_{trench}/CS_{tubular\_liq}$ shows the agreement between the estimated liquid volume and the actual volume. Values over 1 mean the trench will have greater volume than the estimated volume. Again, Botero [2] and Martí-Herrero [5] dimensions yield values below 1, which means that the trench is smaller than the liquid volume recommended in the design. The rest of dimensions recommended by the listed authors give a value over 1, due to the fact that the trench dimensions are overestimated respect to the circumference of plastic available in each case, in concordance with the $L_{bell}/b < 1$.

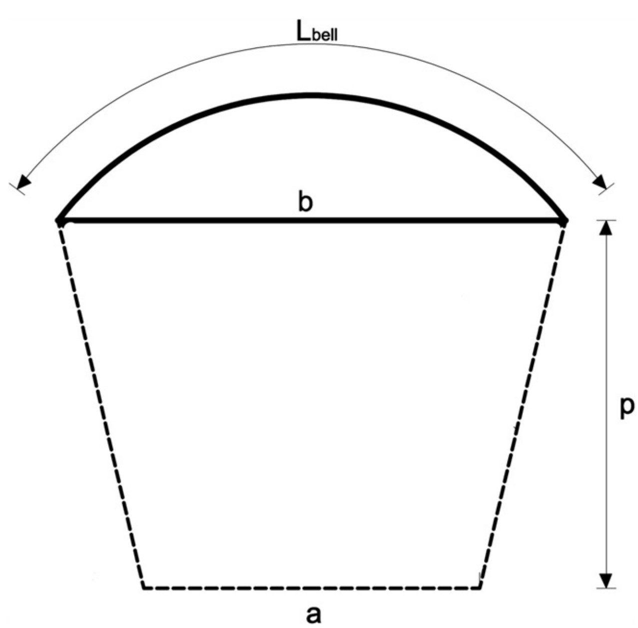

Fig. 1 – Geometrical parameters for the tubular low-cost digester installed in a trench.

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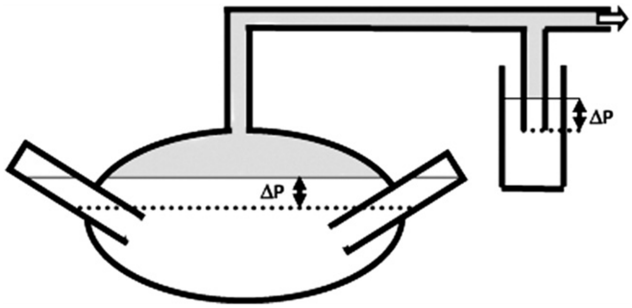

Fig. 2 – Schematic design of a tubular digester and the action of the pressure over the liquid level.

If $CS_{trench}/CS_{tubular\_liq} < 1$, the lower liquid volume could be compensated for by adding length to the digester, but this is not the case in the literature: all the authors calculate the length considering a cylindrical cross section. This design calculation error results in lower real liquid volumes and a lower HRT, which in turn affects the expected performance of the digester. The actual HRT is reduced to 49% of the estimated HRT in the case of Botero [2], and reduced to 84–94% in the cases of Martí-Herrero [5].

In conclusion, to size the digester considering only the cylindrical cross section and not the trapezoidal one dictated by the trench is a common error. A revised methodology is needed which uses the cross section of the trench to correctly calculate the liquid volume as well as the HRT.

3. Influence of biogas pressure on HRT

The basic design of a low-cost tubular digester is shown in Fig. 2. The biogas pipeline begins at the biogas bell and passes a safety valve. This valve is very simple and consists of a "T" in the gas pipeline, the bottom of which is left open and submerged in water in order to let the biogas escape if the pressures of the biogas reaches a value higher than the water column. Therefore, the depth of the pipe inside the water determines the maximum pressure allowed in the system.

The low-cost digester is physically similar to the security valve since it is filled with a liquid than can be displaced by the pressure of a biogas volume out the open influent and effluent pipes.

So if the maximum pressure in the security valve is established—for example at 980.64 Pa, equivalent to 10 cm of water column—the biogas in the system also reaches this pressure and the level of the liquid inside the digester will descend 10 cm, resulting in a lower liquid volume and a lower HRT.

The reduction in HRT due to this issue is 15% less for the estimated liquid volume from the trench dimension in the case of Botero [2] and 11–17% less in the cases of Martí-Herrero [5], for 980.64 Pa.

4. Conclusions

It is a common error to design digesters based on the theoretical cylindrical volume rather than the real volume. The result is a lower final liquid volume yield and a lower hydraulic retention time than expected.

Another error is the failure to consider the influence of the biogas pressure in the liquid level inside the digester. This oversight further reduces the actual HRT.

Neither of these two errors is addressed in the existing literature and both can be observed in the design of low-cost tubular digesters installed around the world. Considering both the pressure effect and the common geometric design methodology, the actual installed HRT could be 44–69% lower than the HRT calculated in the design phase. This would explain the reduced biogas production yield, and justify the end-user complaints about biogas production rates.

Tubular digesters should be designed using the trench cross section and accounting for the decrease in the liquid volume of the digester due to the pressure increase. The question now is: what are the optimum dimensions for the trench given the different circumferences of plastic available?

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