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RURAL BIOGAS TECHNOLOGY: EFFECT OF DIGESTER PRESSURE ON GAS RATE AND COMPOSITION

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Abstract — The effect of digester pressure on gas rate and composition was studied using an experimental Chinese-type digester of 5 m^3 volume. Water buffalo dung was used as feedstock and was fermented at 40 days retention time. The increase in digester pressure was accompanied by a decrease in the amount of biogas produced. However, this decrease was partially compensated for by the increase in methane content. The latter may be attributed to the transfer of carbon dioxide from the gas phase to the liquid phase. The remainder of the noted decrease in the obtained gas amount was related to the increase of the nonconfined amount of slurry in the outlet chamber. Thus, it can be concluded that the initial amount of gas liberated was not a direct consequence of varying the digester pressure. A modified design for the outlet chamber is proposed. Such modification is anticipated to decrease the gas losses, partially stabilize the gas pressure and accordingly increase the efficiency of the digester operation as well as the gas combustion process.

INTRODUCTION

Biogas is a combustible gas consisting mainly of methane and carbon dioxide. It is produced by confining organic matter in an anaerobic digester and is used as a gaseous fuel. Digested slurry, or the stabilized effluent, is a coproduct of this bioconversion process. It is usually applied to land to act as both soil conditioner and fertilizer. Anaerobic digestion is also an effective waste-treatment technique whereby pollution is controlled to a considerable degree.

Currently, biogas technology is available at various levels of sophistication [1–7]. However, in Egypt, as in many other developing countries, attention is focused on intermediate, rural-type technologies appropriate to prevailing rural conditions.

Village-type appropriate biogas technology has undergone major developments particularly in China and India [1–2]. Thus, in China, more than 7 million digesters are in operation [3]. In India, about 110,000 biogas plants are estimated to be existent by the end of 1980 [8]. The Chinese fixed-dome digesters are less expensive to build since they do not incorporate a moving gas holder. However, they have some disadvantages [9]. Among these, the following may be listed:

(1) The gas pressure can be as high as 100 cm water column. This relatively higher pressure than that of the Indian type, which is normally in the order of 10 cm water column, imposes more demanding constructional techniques and precautions and may adversely affect the overall efficiency of the plant.
(2) The gas pressure is constantly varying, which does not permit efficiency maximization of gas-use devices.
(3) An appreciable amount of gas is lost, mainly from the outlet chamber.

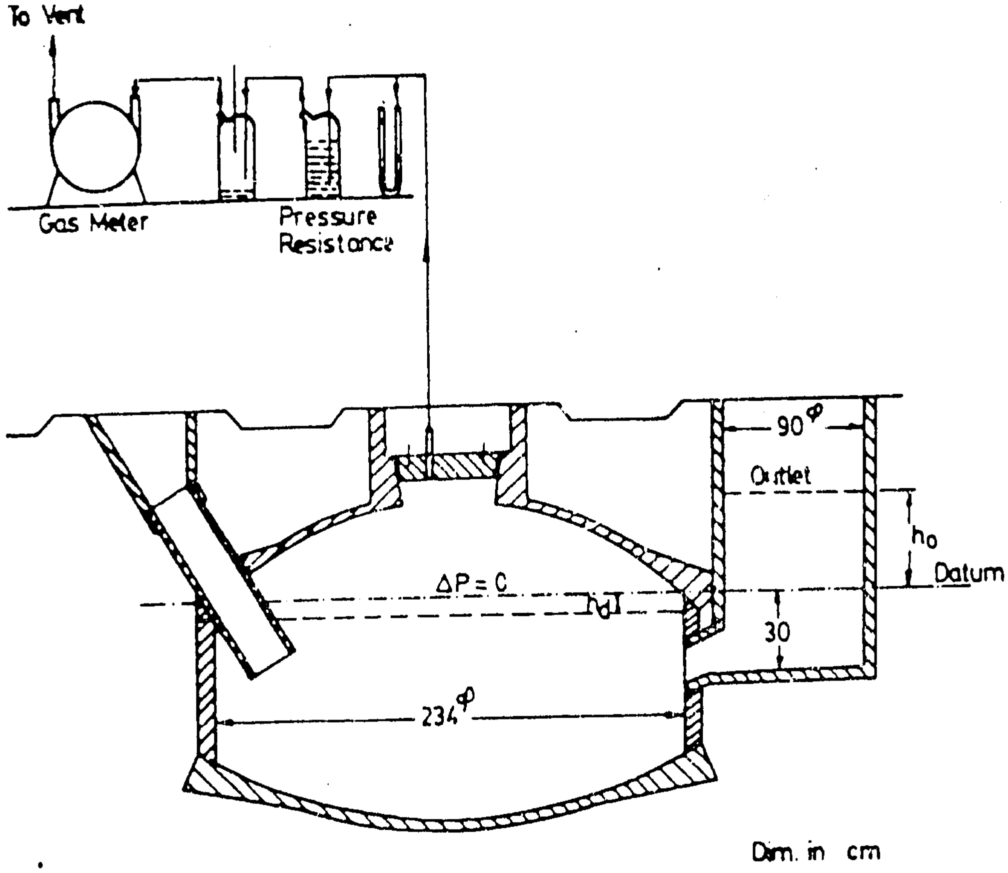

Fig. 1. The 5 m³ digester and experimental setup.

Numerous publications concerning the various aspects of biogas technology have appeared in the recent literature [1–7]. Surprisingly enough, the effect of the digester operating pressure is totally ignored. Therefore, the aim of this study was to clarify the effect of digester pressure on gas rate, composition, and losses. An attempt was also made to increase the efficiency of the Chinese-type digesters by developing a modified outlet chamber design.

EXPERIMENTAL

A shallow and circular Chinese-type digester was used for the study. A small size unit of 5 m³ volume was operated on water buffalo dung of 9%–10% solid concentration. The retention time was held at 40 days.

The digester pressure was fixed at a given level by forcing the gas liberated to pass through a water-column resistance according to the required pressure. Thus, the gas pressure inside the digester was held constant during the duration of the experiment. The gas liberated after reaching the required pressure was steadily vented to the atmosphere. The experimental setup is shown in Fig. 1. More details about the design and construction of the unit were published earlier [10].

TABLE 1

EFFECT OF DIGESTER PRESSURE ON GAS RATE, COMPOSITION, AND LOSSES

Operating Conditions			Gas Production		Gas Composition % volume			Methane production m^3/day	Gas losses m^3/day	Methane losses m^3/day	Total methane m^3/day
ΔP cm H_2O	Pressure mm Hg	Temp. °C	m^3/day	m^3/m^3-day	CH_4	CO_2	H_2				
3	741	23	—	—	53.51	45.95	0.54	—	—	—	—
7.5	744	22.5	0.958	0.238	61.66	38	0.34	0.590	0.055	0.034	0.624
20	755	22.9	0.883	0.223	64.78	33.44	1.78	0.572	0.067	0.043	0.615
37	767	23.2	0.828	0.214	75.42	24.43	0.15	0.624	0.083	0.062	0.686
55	780	24.0	0.758	0.201	76.58	23.36	0.06	0.580	0.098	0.075	0.655
70	785	24.0	0.717	0.195	74.91	25.01	0.08	0.537	0.105	0.078	0.615

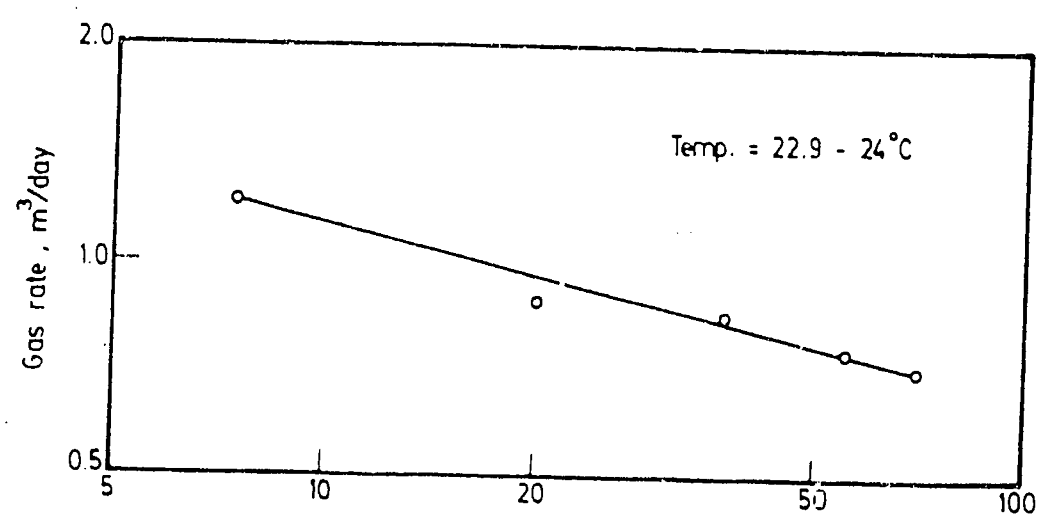

Fig. 2. Effect of gas pressure inside the digester on the available gas rate.

Since the operating pressure limits of the Chinese-type digester are usually between 0–100 cm water column, the range of 3–70 cm water column was used in this study. The digester was allowed to operate for some days after changing the pressure to reach steady-state conditions, after which the volume of the gas liberated per day was measured using a gas meter. The gas volume liberated at the predetermined pressure head was measured for 3–4 days, and a mean value was taken. One sample of the gas at each pressure was analysed by chromatography. The conditions of the experiments are given in Table 1.

RESULTS AND DISCUSSION

The gas production rates obtained at different pressures are given in Table 1 and are shown graphically in Fig. 2. The volume of gas obtained per day decreased with

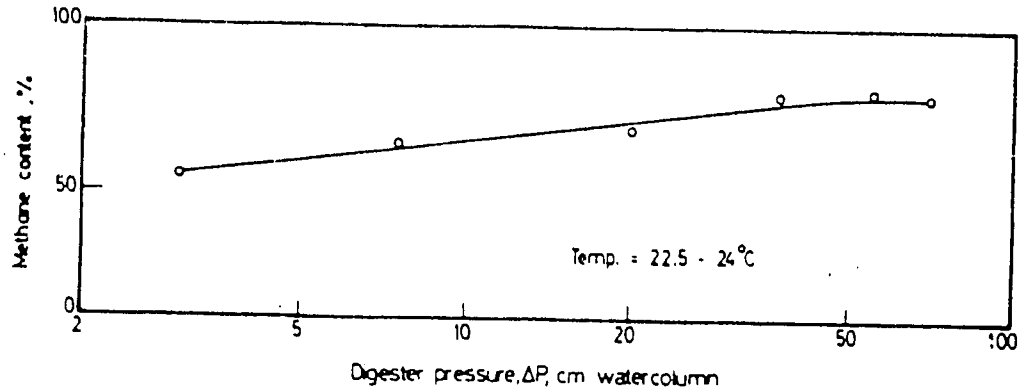

Fig. 3. Effect of digester pressure on methane content of gas.

increasing pressure. The gas composition was also affected by increasing the digester pressure. As seen from Fig. 3, the methane content increased with increasing digester pressure reaching a maximum value of about 76% at a pressure of 55 cm water column, after which the methane content tended to have a constant value. This can be attributed to the increase in carbon dioxide dissolution in the liquid slurry with increasing pressure. Thus, the noted decrease in the amount of gas obtained is partially compensated for by the increase in the methane content (the main combustible constituent of biogas).

It should also be noted that increasing the pressure inside the Chinese-type digester increases the dead slurry volume present in the outlet chamber. Since the gas generated from this portion of slurry is generally not collected, it would thus represent a loss and contribute to the prevailing decrease in gas production rate. Evaluation of the effect of this parameter on the gas rate is therefore very important and is further discussed below.

The typical family-size Chinese-type digester used in this study is shown in Fig. 1. At zero pressure, the level of the slurry is the same in both the digester and its outlet part. At this condition, in the Chinese design, the slurry height in the outlet chamber ranges between 48 cm for the 6 m^3 digester and 64 cm in the 12 m^3 digester. In the 5 m^3 digester used in the present study, this height was equal to 30 cm, which is very close to the similar Chinese design.

If the level at zero pressure is taken as the datum line, then as soon as some gas is liberated and collected in the dome, the pressure inside the digester is increased, forcing the slurry from the digester to the outlet chamber. Accordingly, if the liquid level in the digester decreases by a height (h_d), the same slurry volume displaced will increase the liquid height in the outlet chamber by (h_o) (neglecting the feed line due to its small volume).

Let digester diameter = d_d and outlet diameter = d_o, then,

$$\frac{\pi}{4} d_d^2 h_d = \frac{\pi}{4} d_o^2 h_o \tag{1}$$

or

$$h_d = h_o \frac{d_o^2}{d_d^2}; \tag{2}$$

$$\text{digester gauge pressure} = \Delta P = h_d + h_o = h_o \frac{d_o^2}{d_d^2} + h_o \tag{3}$$

or

$$h_o = \Delta P \frac{d_d^2}{d_d^2 + d_o^2} = \Delta P \frac{(2.34)^2}{(2.34)^2 + (0.9)^2} = 0.87\Delta P \tag{4}$$

$$\text{dead slurry volume} = \left(\frac{\pi}{4} d_o^2 \right) 0.3 + \frac{\pi}{4} d_o^2 h_o . \tag{5}$$

$$\text{dead slurry volume} = (0.19 + 0.55\,\Delta P)\ \mathrm{m}^3 . \tag{6}$$

Using Eq. (6), the dead slurry volume was calculated at the different values of operating pressures employed.

The gas losses from the outlet chamber at different operating pressures are estimated on the basis of the dead slurry volume and the gas production rate. The results are given in Table 1. They clearly indicate that the gas losses are appreciable and increase with the increase of operating digester pressure.

Table 1 indicates a small change in the total amount of methane available from both digester and that estimated from the outlet chamber, and is not appreciably affected by changing the pressure. The small deviations in these results can be attributed to the effect of minor operating temperature variations and/or probable small errors in gas sampling and analysis.

Thus, it can be concluded that the variation of digester pressure in the mentioned range does not affect the fermentation process. The outlet chamber design appears to be a major cause of gas losses. It follows then that attention should be focused on the need for developing a new modified outlet chamber capable of minimizing the gas losses. A possible modification can be based on decreasing the amount of dead slurry in the outlet chamber, while keeping the same effective gas holding capacity of the digester.

The key ideas in the proposed modification are as follows:

(1) The dead slurry volume at zero pressure in the Chinese design is quite high and can be eliminated totally. Thus, the datum line should lie at the bottom of the outlet chamber, or a little lower. The main disadvantage of this modification is that some difficulties can exist in the case of manual discharging of the daily effluent. However, these difficulties can be avoided either by discharging manually at the time of high pressures or by self-flow of slurry through a specially designed overflow at the required pressure.

(2) Change the constant cross section of the outlet chamber into variable one with the smaller diameter at the bottom. Such a design is expected to be suitable for the family size digesters of volumes in the range of 5–12 m^3 and is shown in Fig. 4.

The main advantages of this design are as follows:

(1) Decreasing the dead amount of slurry at low operating pressures, thus increasing the digester efficiency.

(2) At very low pressures ($\Delta P < 20$ cm H_2O), the liberation of even the smallest amounts of gas inside the digester can very quickly affect an increase in gas

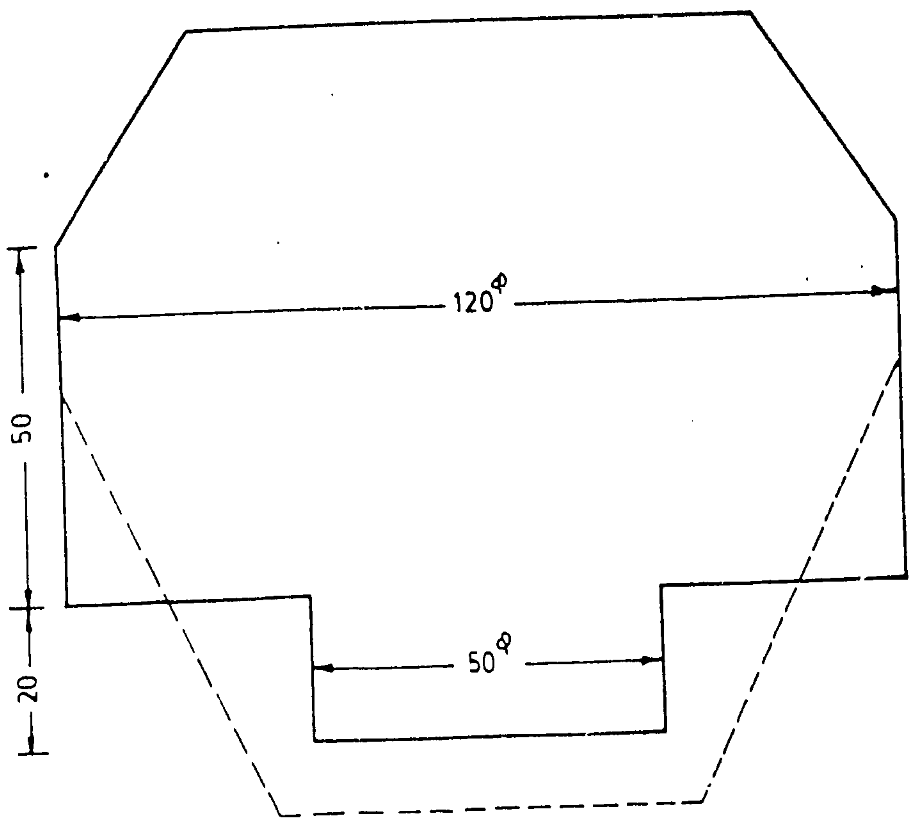

Fig. 4. Modified outlet chamber: (——) cylindrical shape; (----) truncated cone shape.

pressure, thus assisting the functioning of the gas-use devices which would otherwise be inoperable.

(3) At moderate pressures (ΔP = 30–50 cm H_2O), the gas liberated and stored, slowly increases the gas pressure, i.e., the gas pressure becomes more stable. Hence, an increase in the efficiency of the gas-use devices can be attained. It is worthy to mention in this context that the inherent low combustion efficiency of the system and which is considered as one of the main disadvantages of the variable pressure digesters can be partially overcome.

(4) The cross section and heights of the chamber ports can be adjusted in such a way as to minimize gas losses with the required holding capacity of gas, while still sustaining more efficient gas combustion.

Generally, for fixed dome gas holders, the gas-use devices are designed to operate at high pressure. If the operating pressure is taken at 40(+10 or −20) cm water column, then we can define the effective holding capacity as that volume of gas which is available for utilization at any moment, i.e., the volume of gas available at pressures higher than 20 cm water column. The gas volume present at lower pressures cannot be used and thus does not play any role in the effective gas volume.

The effective volume of gas stored was calculated for the different designs based on the above definition by considering the effective gas holding capacity equal to

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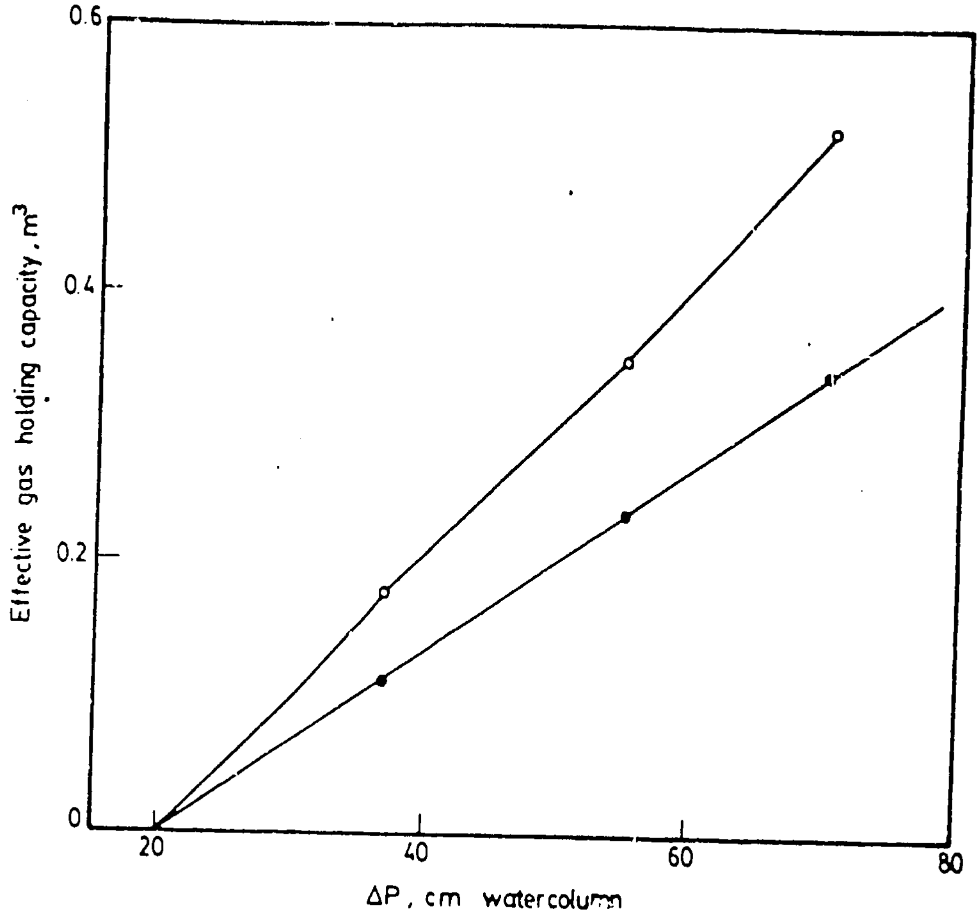

Fig. 5. Effect of gas holding capacity on digester pressure: (●) Chinese design; (O) modified design.

zero at ΔP = 20 cm water column. The volume of gas holder at zero pressure was taken equal one m^3. Figure 5 shows that the modified design (cylindrical shape) decreases the digester pressure sharply while keeping the same effective gas holding capacity. Thus, for the storage of 0.2 m^3 gas, the gas pressure in the modified design is 39 cm H_2O compared to 49.5 cm H_2O for the typical Chinese design. Increasing the stored gas volume to 0.3 m^3 affects an increase in the gas pressure to reach 49.5 cm H_2O in the modified design compared to 64 cm H_2O in the typical Chinese design. Hence, partial stabilization of pressure is attained.

Figure 6 illustrates the gas losses calculated for the modified design compared to that of the typical Chinese design at the same gas holding capacity. A sharp decrease in the gas losses can be noted for the modified design, especially at low and moderate gas holding capacities (0.1–0.3 m^3 for the small family size unit).

It seems to the authors that this study is the first one to stress on the gas losses from the Chinese-type digesters. Very recently, however, it was reported [11] that the Janata-type digester, which is an Indian modification of the Chinese fixed roof digester, produces gas of 20%–25% less than the Indian moving gas holder design. This low gas production rate can be attributed mainly to the losses from the outlet chamber.

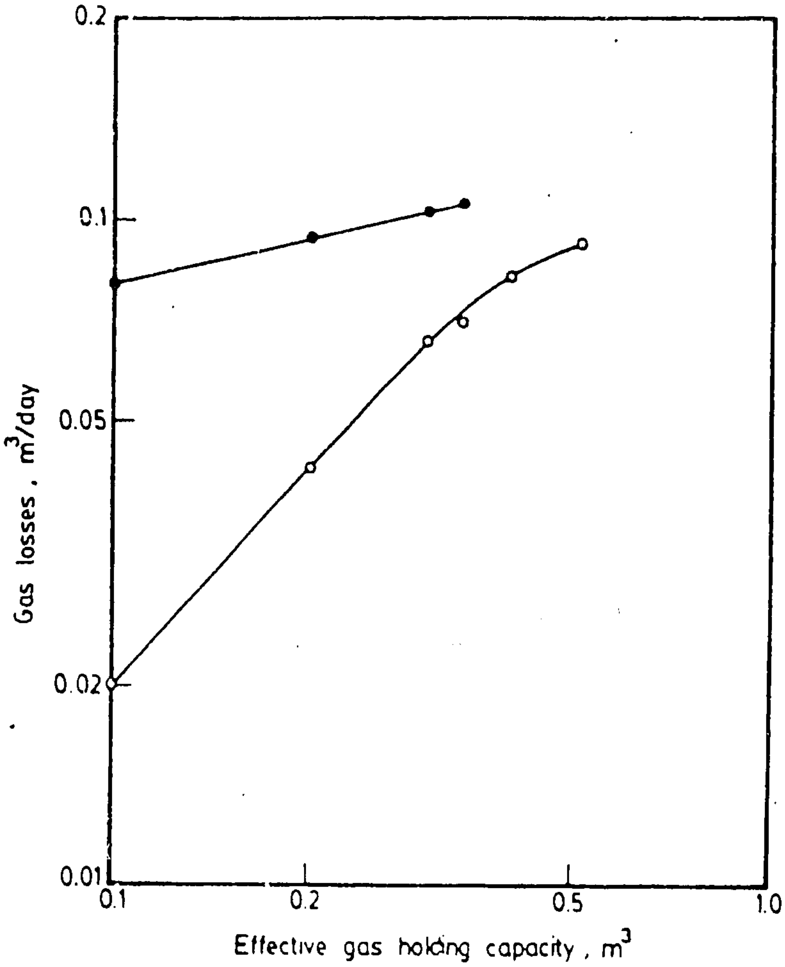

Fig. 6. Effect of gas holding capacity on gas losses for different designs: (●) Chinese design; (○) modified design.

CONCLUSIONS

The gas production rate decreased by increasing the digester pressure. The decrease in gas rate can be attributed mainly to the losses from the nonconfined slurry in the outlet chamber.

The modified outlet chamber is shown to decrease the gas losses and accordingly increases the available gas production rate. The modified design also partially stabilizes the gas pressure. Thus, an increase in the efficiency of the digester operation as well as the gas combustion process is expected.

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