Monitoring of biogas production from fermentation of rice straw using a bubble counting sensor

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Woo, D.H., Hwang, C.H., Chung, I.S. and Chun, J.K. 1997. **Monitoring of biogas production from fermentation of rice straw using a bubble counting sensor**. Can. Agric. Eng. **39**:203-206. A bubble counting sensor with an on-line monitoring system was applied to biogas production from fermentation of rice straw. This simple and low-cost sensor was capable of measuring bubble diameter and counts by a photointerrupter and a clock cycle (2441Hz). The detectable range of gas production rate was 0.067 - 10 mL/min. The on-line monitoring system built with a one-chip microcomputer was operated for over 100 days and demonstrated to be promising in monitoring gas production during fermentation processes. Keywords: biogas production, rice straw, bubble counting sensor, on-line monitoring, fermentation.

Un capteur-compteur de bulles équipé d'un système de surveillance en temps réel a été utilisé pour mesurer la production de biogas à partir de la fermentation de la paille de riz. Avec cet appareil simple et peu coûteux, on est capable de mesurer le nombre et le diamètre de bulles par le photointerrupter et le cycle d'horlogerie (2441 Hz). Le gamme mesurable du taux de production du gaz a été de 0.067 à 10 mL/min. L'ensemble du système a fonctionné pendant plus de 100 jours et a montré un potentiel prometteur pour la surveillance de la production du gaz pour tout procédé de fermentation. Mot clés: production de biogas, paille de riz, capteur pour compter le bulles, surveillance en ligne fermentation.

INTRODUCTION

Methane fermentation of agricultural wastes is becoming of economic and environmental importance. Traditional methane fermentation is a slow process and can be quite sensitive to environmental changes (Chynoweth and Jerger 1988; Clausen et al. 1979). In methane fermentation, inherent problems exist due to unstable characteristics of the process (Renard et al. 1988; Salm 1984). In this respect, an efficient monitoring system for the methane fermentation process is required. This can be achieved by on-line detection of the biogas during the fermentation process.

The gas production rate has been successfully monitored using a bubble counting sensor in aerobic and facultative processes such as for yeast and Kimchi fermentation (Lee and Chun 1994; Choi and Chun 1996). However, there is no information available on monitoring gas production by this type of sensor in an anaerobic process. In this study, the development and performance of the sensor were studied for on-line monitoring of gas production in methane fermentation of rice straw.

MATERIALS AND METHODS

Correlation between orifice diameter and bubble diameter

The bubble sensing apparatus was constructed of a glass column of 10 mm diameter and 100 mm height, an acrylic orifice plate (replaceable), two photointerrupters (EESB5), and an air-tight syringe, as shown in Fig. 1. A set of experiments was carried out in triplicate at 25°C with a known volume of air (4 mL) and various diameters of acrylic drilled orifice plates to establish the correlation between orifice diameter and bubble diameter. Air was injected by a calibrated gas-tight syringe into the column and the air flow rate was controlled by adjusting the speed of the plunger. The ascending bubbles were detected with the photointerrupter. The acrylic plates of 1 mm thickness had orifice diameters of 2.3, 2.7, 3.2, 3.25, 3.8, 4.2, and 4.8 mm. At a given diameter of orifice, the average ascending bubble velocity (u_b) was calculated by dividing the distance between the two photointerrupters by the time taken for the bubble to travel. Assuming the bubble to be spherical and uniform in size at a given ascending velocity, the volume of a bubble was determined by injected air volume and bubble counts at a fixed air flow rate. Average bubble diameter (D_{av}) was calculated by:

$$D_{av} = (6V/\pi)^{1/3} \qquad (1)$$

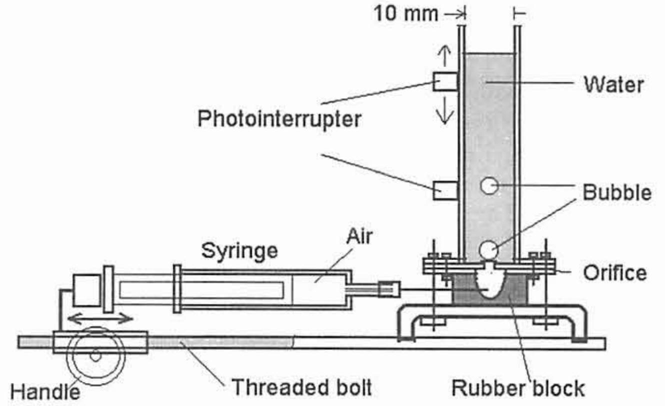

Fig. 1. Schematic diagram for bubble sensing apparatus.

where V = volume of a bubble. The photointerrupter produced square pulses in response to the bubble passage. Based on the hypothesis that the bubble diameter (D_b) should be equal to the width of the square pulse, its width was calculated using a known clock of 2441Hz (cycle width : 0.052×10^{-4} mm) as described by:

$$D_b = W_{pp} = f\, W_{cc} \qquad (2)$$

where:

W_{pp} = width of a square pulse (at high logic duration) produced from the photointerrupter (mm),
f = multiplying factor (number of clock cycles counted during one pulse duration of the photointerrupter signal), and
W_{cc} = width of clock cycle.

Modified bubble counting sensor

The bubble sensing apparatus was further modified to fabricate a practical sensor for measuring the biogas production rates in methane fermentation. Figure 2 shows the modified bubble- counting sensor consisting of bubble formation (A) and count (B) sections. The weir was provided to prevent liquid from flowing in a reverse direction when reduced pressure developed at the gas inlet during fermentation. Section A was filled with distilled water and the liquid height was maintained at 10 mm water over the orifice plate. The orifice diameter of the sensor was 3.25 mm. Section B was equipped with the photointerrupter for detection of bubbles. This bubble counting sensor was also calibrated with the known gas volume in a way similar to that described above.

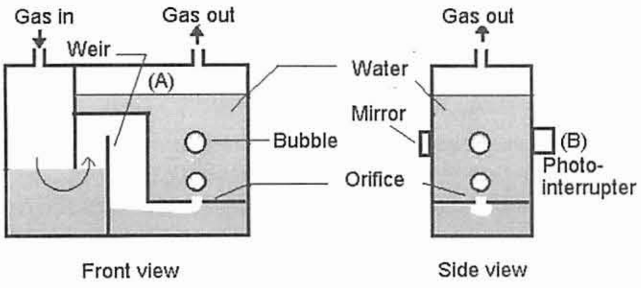

Fig. 2. Schematic diagram of modified bubble counting sensor.

Fermenter and monitoring system

A fermenter with working volume of 20 L was used for the experiments (Fig. 3). The fermenter had an outer vessel, which was used as a water jacket with an electrical heater (500W). The fermenter lid had a vent hole and 150 mm-depth-weir. The sensor was mounted at the lid of the fermenter and the tygon tubing (100 mm) was connected between the biogas outlet and the sensor inlet (Fig.3). The biogas was eluted via the vent hole into the bubble counting sensor since the weir was used to prevent gas leakage. The one-chip microcomputer-based controller was built with a microcontroller (MC68705R3, Motorola, 1983) to acquire the bubble count and control the temperature of water jacket on a real time basis.

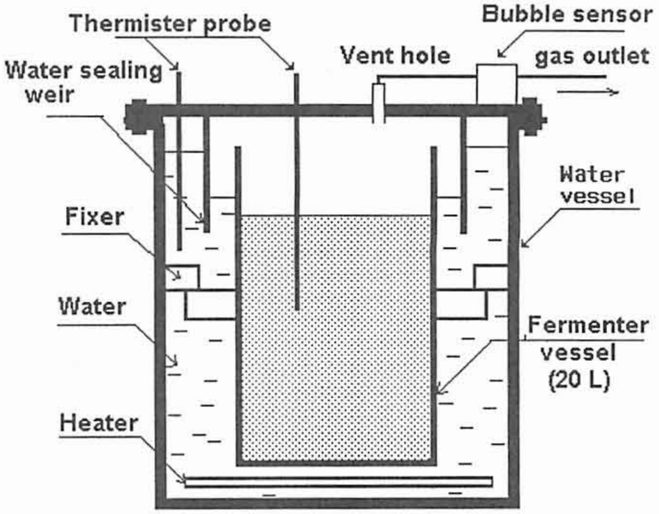

Fig. 3. Schematic diagram of fermenter.

Substrate preparation and inoculation

Five hundred grams of rice straw were cut into length of 30 mm and treated with 5 liters of 1N sodium hydroxide solution at 55°C for 24 h to make it more digestible (Hashimoto 1986; Pavlostthis and Gossett 1985). The pretreated rice straw was adjusted to pH 7.0 and was supplemented with urea for a C/N ratio of 30 to 40. The mixture was placed in the fermenter maintained at 35°C where pig manure was subsequently seeded by 20% of the total volume.

Analysis of biogas

The gas composition was analyzed by a gas chromatograph (Pye Unicam PU4500, Eindhoven, The Netherlands) equipped with FID. The column used was Porapak Q 80/100 (stainless, 1.2 m, 0.32 mm OD). The temperature of the injector, column, and detector were 40°C, 40°C, and 100°C, respectively. The carrier gas was nitrogen and its flow rate was 15 mL/min.

RESULTS AND DISCUSSION

Correlation between orifice diameter and bubble diameter

Ascending bubble velocity (u_b) was inversely proportional to orifice diameter (Fig. 4) and it was not affected by the height of water in the range of 10 to 50 mm. It is apparent that the ascending bubble velocity was constant at a fixed orifice diameter of the sensor.

The average diameter of air bubble (D_{av}) is related to the orifice diameter at 25°C by the expression (Fig. 5):

$$D_{av} = 0.1654\, d_o + 4.449 \qquad \text{for } 2.7 < d_o < 4.8 \qquad (3)$$

where d_o = orifice diameter.

It was also found out that the measured bubble diameter is close to the average bubble diameter with a percent difference being within 2% (Table I). Thus, it should be mentioned that the method of bubble counting by this sensor is quite reliable.

Modified bubble counting sensor

The bubble sensing system was further modified (Fig. 2) to

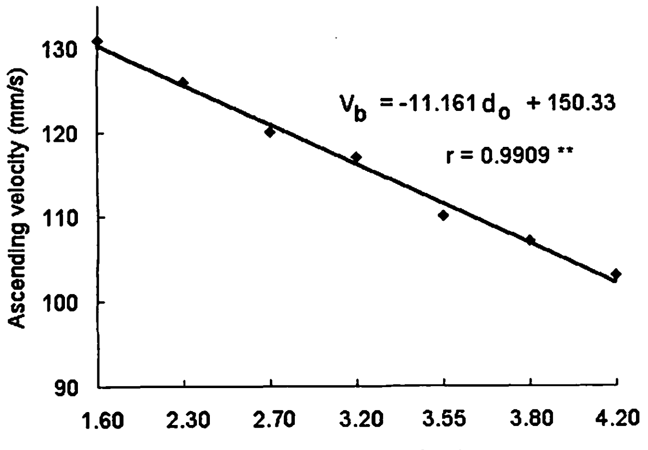

Fig. 4. Relationship between ascending bubble velocity and orifice diameter. The apparatus shown in Fig. 1 was used at 25°C.

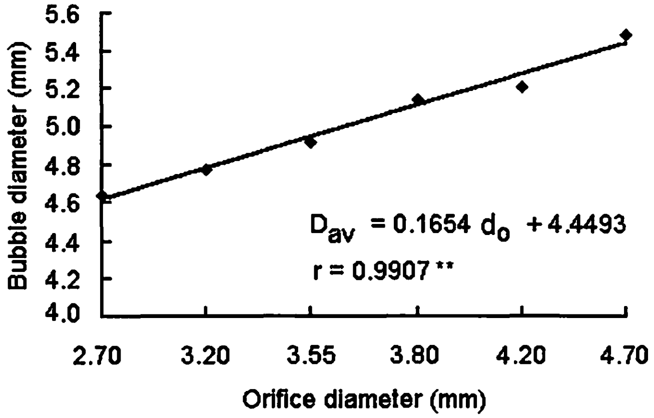

Fig. 5. Relationship between average bubble diameter and orifice diameter. The apparatus shown in Fig. 1 was used at 25°C.

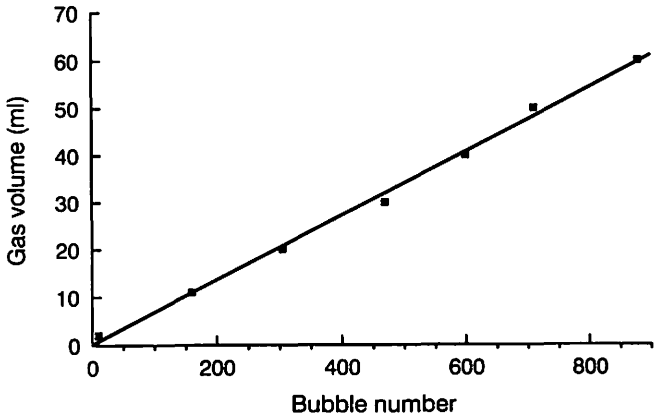

Fig. 6. Relationship between gas volume and bubble number at 25°C. The orifice diameter was 3.25 mm.

measure the biogas production rates in methane fermentation. This was identical to the system in Fig. 1 except that the liquid height was maintained at 10 mm over the orifice plate and the air inlet resistance by weir exist. The modified bubble counting sensor was also calibrated with the known gas volume as shown in Fig. 6. The volume was proportional to bubble counts with the linear relationship:

$$V = 0.06696\,N \tag{4}$$

where:

V = gas volume (mL), and
N = bubble count.

The detectable range of this sensor was 0.067 - 10 mL/min with an orifice diameter of 3.25 mm since within this range no overlapping pulses were observed. Our finding indicates that the bubble count can be used as a real time indicator of gas production from fermentation of rice straw.

Monitoring of biogas production from methane fermentation

As shown in Fig. 7, the gas production rate was successfully monitored for over 100 days. The gas production rate gradually increased up to 40 days and reached the maximum level

Table I: Comparison of measured bubble diameters with predicted values at various orifice sizes

Orifice diameter (mm)	Bubble count[1] (count)	Bubble volume[2] V_b, (mm^3)	Bubble diameter (mm)	
			Measured (D_b)	Predicted (D_{av}) with Eq. 3[3]
2.85	63.8 ± 0.922	62.7	4.93	4.92
3.25	58.4 ± 0.933	68.5	5.07	5.07
3.80	53.9 ± 0.555	74.2	5.21	5.21

[1] Bubble counts for 4 mL of air volume (being injected sufficiently slowly as not to form overlapping bubbles). Values are mean ± SD for number of runs = 60.

[2] Calculated by known air volume (4 mL) divided by bubble counts (Fig. 1).

[3] Regression coefficient between orifice diameter and bubble diameter was 0.9907** (significant at 1% level).

on day 43. This result reveals that this sensor can be applicable for monitoring the gas production rate during the extended period of fermentation.

Another experiment was conducted to analyze the gas production and composition during a 30 day period of fermentation of rice straw. The gas production rate increased abruptly at day 2 and became negligible on the 10th day. Thereafter, the rate increased sharply from 0 to a peak 10 L/d on the 14th day and remained relatively high until the 21st day. Gas analysis showed that the onset of actual methanogenesis had occurred about the 11th day after the initial fermentation stage. Methane concentration in biogas was negligible at the early stage, became relatively constant after the onset of methanogenesis, and remained high at about 80% of the total biogas during the stage of methanogenesis. There also appeared to be an initial lag time of 24 h in the bubble formation. This was probably due to the time needed for the pressure to build up and form the first bubble in the sensor. It turned out that the onset of methanogenesis can be easily detected with this bubble counting sensor. Therefore, it is apparent that the sensor with on-line monitoring system would be a useful device for monitoring methane fermentation processes.

The manufacturing cost of this gas sensor was less than $10, which would be much cheaper than the one on the market. The limitation of this sensor lies in its narrow detectable ranges. To apply it to a large scale digester, the refinement of this gas sensor must be further investigated. However, our findings indicate that this simple and low-cost bubble counting sensor seems promising for monitoring the gas production rate of an anaerobic system such as methane fermentation. This work also demonstrates that a one-chip microcomputer-based controller was suitable for data acquisition and monitoring of methane fermentation.

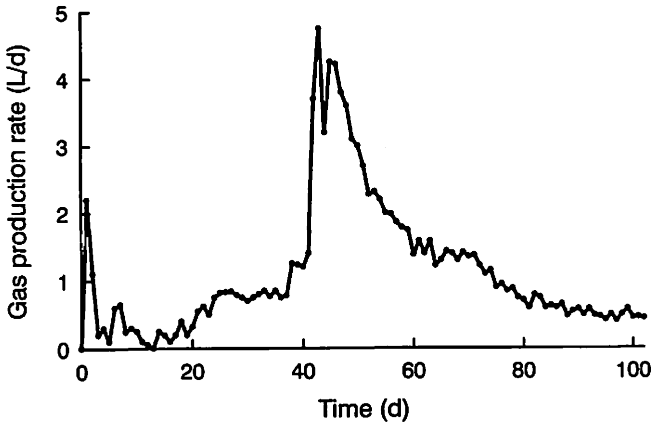

Fig. 7. Gas production rate in the fermentation system as a function of time. The fermenter was maintained at 35°C and pig manure was seeded by 20% of total volume.

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