The influence of temperature and total solid concentration on the gas production rate of a biogas digester

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Abstract
In the present investigation, laboratory level experiments were carried out to investigate the effect of temperature and total solid concentration on the performance of biogas digesters. The gas production rate with batch model type of digesters was studied under controlled as well as uncontrolled temperature conditions. In each case, cattle dung-water mixture with total solid (TS) concentration of 2.5%, 8% and 12.5% were considered. In the case of biogas production, digesters were maintained at constant temperatures of 30°C, 35°C, 40°C and 45°C. The weekly pH value in each case has also been monitored. The present investigation shows an increase of gas production under a controlled temperature of 35°C and with 8% TS concentration.

Keywords: gas production, biogas digester, biogas production, temperature

Introduction

The development of alternative fuel sources began well before 1970, however, the interest in producing biogas from waste peaked during the seventies because of the rising price of fossil fuels. As the cost of petrol and diesel is continuously increasing, currently the emphasis is being given to the production of biogas. It has also been realized that biogas produced from cattle-dung is not only economical but also environment friendly (Wise 1987).

Cattle dung is found in abundance in India, and most farmers use it as a fertilizer for cultivation of vegetables, a paddy, etc. The vast majority of the people living in villages use wood as a primary source of fuel, where wood is readily available and cheaper than kerosene. In addition, small industries producing bricks, ceramics, lime, sugar etc. also use firewood. However, the drive to preserve nature and its environment puts a limit on the usage of wood as a fuel. This has resulted in an increased importance in the use of biogas in recent years (Khandelwal & Mahdi 1986; Mittal 1996). Although the composition of local dung is likely to be different from countries like South Africa, the investigation reported in this paper would be useful in formulating and designing an improved biogas digester needed for a particular region.

It is well understood that the efficiency of anaerobic digestion essentially depends on the intensity of bacterial activity. Hence, it is important to regulate the factors that affect the bacterial activity (Mittal 1996). Numerous investigations have been undertaken in the past few decades by a host of researchers to understand the behaviour and performance of biogas digestion.

In the 1930s, Bushwell and Hatfield (1996) identified the anaerobic bacteria and the conditions that promote methane production. Further advancement in this aspect has also been reported (Qasim, & Stinehelfer 1982; Aburas et al 1995; Qasim et al 1984). However, literature on thermochemical factors affecting the biogas production rate is limited. Lusk has studied several types of digesters with internal heating (Lusk 1998), and observed that the gas production is maximum in the mesophylic temperature range. Studies on the effect of biomass concentration and pH values on gas production rates have also been reported (Wise 1987; Khandelwal & Mahdi 1986; Mittal 1996; Bushwell & Hatfield 1996; Lopez et al 1992; Safly 1990). Rahman (1996; 2002) investigated the functional design of a mixed-feed system and developed a relation between the gas production rate and concentration of different mixed biomasses. It has also been observed that the digestible content in the excreta of cattle strongly affects the biogas production (Safly 1990; Rahman 1996). In the light of the above facts, it has been felt that there is a need to carry out a detailed study of a biogas digester by controlling its temperature and varying the feed material.

Present investigation

In the present investigation, experiments were carried out in a laboratory, with batch type digesters. Altogether, fifteen digesters having the same capacity were used. Digesters 1-3 were kept at an identical temperature, and were fed with three different total solid concentrations. Similar arrangements had been made for other digesters. At a particular temperature, digesters were fed with cattle dung-

water mixture, with three different total solid (TS) concentrations of 2.5%, 8% and 12.5%. Each experiment was carried out thrice to check the test repeatability, and data was averaged and plotted. As stated earlier, the effects of temperature, pH values and TS concentration levels on biogas production rate have been studied.

Materials and methods

A typical set-up developed consists of a round bottom flask filled with the specimen and is used as a digester having a capacity of 2.5 litres (Figure 1). One end of a flexible pipe is connected to the neck of the flask, while the other end is inserted in an inverted measuring cylinder. The measuring cylinder is dipped in a tank containing water. A thermometer inserted at the top of the flask measures the temperature of the mixture fed into the flask. The opening of the valve at the top of the inverted cylinder allows release of gas. The system uses the water displacement method for the measurement of biogas production. Initially, a mixture of cattle dung and water is fed into the digester (flask), and its inlet is sealed to prevent leakage of gas. Samples prepared were fed into the digesters from the same raw material. The quantity of biogas produced is monitored from the measuring cylinder. The constant temperatures of the digesters were maintained by using a thermostat control. This arrangement is made by connecting an immersion heater and a thermostat in series, with a single-phase power supply. The immersion heater and thermostat rod are inserted in a water bath to maintain a particular temperature inside the digester. The water bath was insulated with the help of ceramic insulation to reduce the heat loss.

The volume of the measuring cylinder considered in the present investigation is 500 ml. The temperature of the mixture in the digester was measured once in every four hours, and the pH value was recorded on a weekly basis. Cattle dung with carbon and nitrogen ratio (C / N ratio) 25.6 is used for all the cases. The properties of the cattle dung at three different total solids as well as four different temperatures are shown in Table 1. It is clear from this table that the digester with 8% TS, 75% VS (volatile solid) and 35°C provide more biogas yield per kg of cattle dung and this value (25.74 litres / kg) falls nearest to the standard case (32 litres / kg).

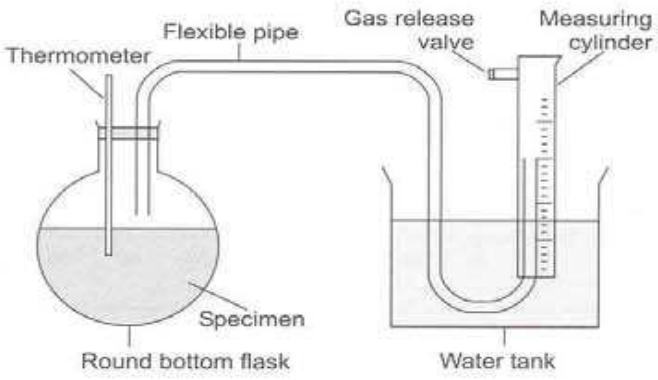


Figure 1: Schematic diagram of the setup

Results and discussion

The gas production rate for all the total solid (TS) concentration level was recorded on a daily basis for a period of 55 days. This retention time of 55 days has been recommended for the northeast of India (Khandelwal & Mahdi 1986). Results for each of the total solid concentrations were analysed on a daily basis (averaged on 4 hourly recorded data). The present results of gas production per day and cumulative gas production rate for a period of 55 days are compared with the results of Chowdhury (1987) and Maramba (1978).

The variation of gas production rate at controlled digester temperature of 35°C is presented in Figure 2. The maximum gas production at this temperature is observed in the third week. Chowdhury and Maramba, who used a starter in their feed material, made a similar observation, however, the maximum gas production was found to be 1.8 times more than the present results for the same volatile solid concentration. The higher gas production rate obtained by Chowdhury and Maramba is probably due to the use of a starter, which causes the microbacterial activity to become fast, hence, increases the gas production sharply in the beginning. However, the gas production rate decreases after the third week that is much less than the value obtained in the present investigation. On the other hand, the cumulative gas production rate in the present investigation, for a hydraulic retention period of 55 days, shows a similar pattern and is found to be 1.107 times more than the results of Chowdhury and Maramba.

Table 1: Properties of cattle dung

TS concentration	*VS*	*Gas production in litres/kg*				
		30°C	*35°C*	*40°C*	*45°C*	*Uncontrolled temperature*
2.5%	64.5%	9.85	6.71	1.10	31.02	12.70
8%	75.0%	15.67	25.74	10.94	19.47	8.69
12.5%	66.7%	6.82	13.55	2.24	0.54	4.97

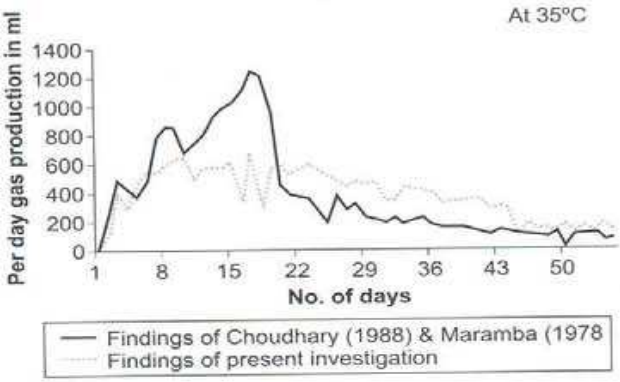


Figure 2: Comparison of gas production per day

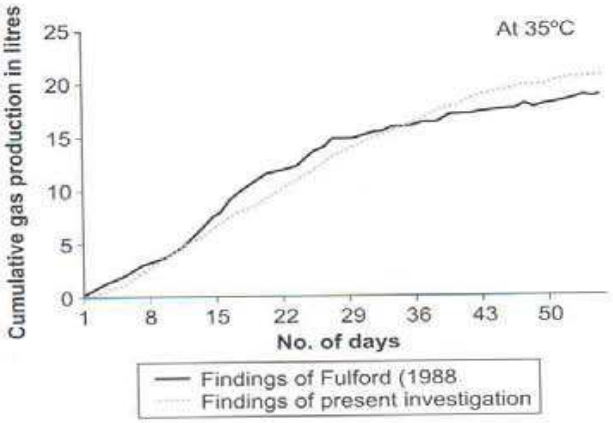


Figure 3: Comparison of cumulative gas production

The gas production rate per day under both controlled and uncontrolled temperature conditions with three different concentrations viz., 2.5% TS, 8% TS and 12.5% TS have been presented in Figures 4 – 6 respectively. From these figures, it is seen that per day variation of gas production rate is different at different temperatures up to the fourth week, however, after the fourth week the gas production rate shows a similar pattern and diminishes randomly towards the end of the retention period. This is probably due to the reduction of protein requirement to the microbacteria, as they cannot work in a less-protein environment. This may be one reason why there has been low gas production towards the end of the retention time.

At 2.5% TS, the gas production is maximum (870 ml) at 45°C and in the third week, and thereafter it decreases randomly. As observed in Figure 4, the variation of controlled temperature at 30°C, 35°C and 40°C has shown little effect of temperature in the gas production rate. But the variation of gas production in the case of uncontrolled temperature shows a different trend where the gas production is zero in the first week, and then starts rising from the second week onwards and reaches its

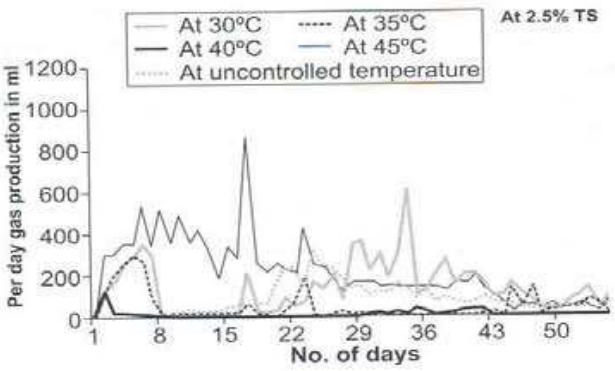


Figure 4: Gas production rate for 2.5 %TS

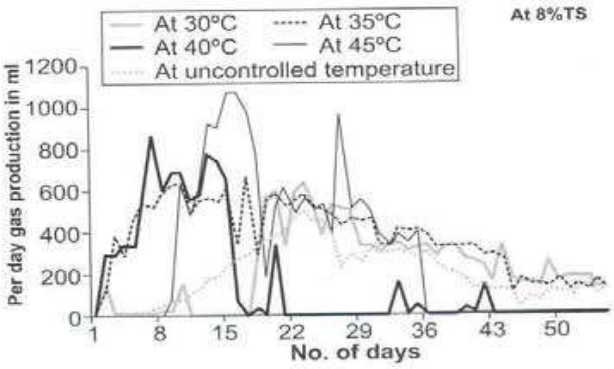


Figure 5: Gas production rate for 8 % TS

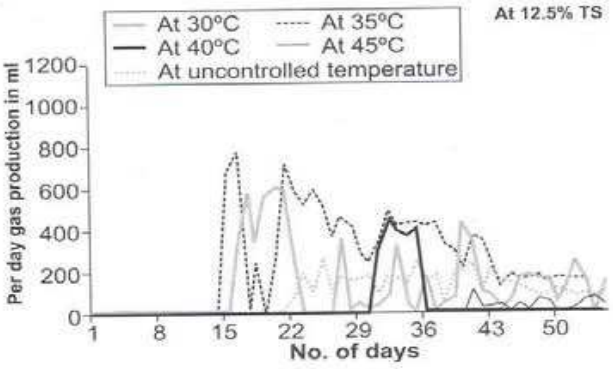


Figure 6: Gas production rate for 12.5 % TS

maximum value of 310 ml in the fourth week (Figure 4). The production rate decreases from the fifth week onwards.

At 8% TS (Figure 5), it is observed that the maximum gas production per day varies with temperatures and periods. The maximum gas production of 1100 ml and 680 ml has been observed in the third week at 45°C and 35°C respectively, whereas it shows a value of 650 ml and 500 ml in the fourth week at 30°C and uncontrolled temperature respectively. Again at 40°C, the maximum gas production

goes to 890 ml by the end of first week, thereafter, it decreases randomly towards the end of retention time.

At 12.5%TS (Figure 6), gas production is small up to the second week for all the cases with the exception at 45°C, thereafter, it increases sharply and reaches a maximum value of 780 ml and 615 ml in third week at 35°C and 30°C respectively. The production rate goes to 450 ml and 250 ml in the fourth week and at the beginning of the fifth week at 40°C and at uncontrolled temperatures respectively. The gas production at 45°C is much less as compared to the other temperatures.

From the above analysis, it can be interpreted that with lowest TS content of 2.5%, the thermophyllic temperature range (higher than 40°C) is optimum for maximum gas production, whereas the mesophyllic temperature in the range of 30°C to 40°C is found to be suitable for high biogas yield with higher total solid content of 8% and 12.5%. From the above study it is seen that gas production is maximum at 8% TS and at 35°C.

The cumulative gas production in all the cases is shown in Figures 7 – 9. It has been observed that except at 2.5% TS (Figure 7), for all other cases, provides a large gas yield at 35°C. The cumulative data taken over a period of 55 days for all the three cases is shown in Table 2. It is clear from the table that the gas production rate is maximum at 45°C with 2.5% TS. Furthermore, the gas production rate at this temperature is 1.56 times, 4.63 times, 27.6 times and 2.43 times more than those obtained at 30°C, 35°C, 40°C as well as uncontrolled temperature respectively. Low gas production has been observed at 40°C. At 8%TS (Figure 8) gas production is maximum (21.395 litres) at 35°C, which is 1.64 times, 2.35 times, 1.32 times and 2.95 times higher than those obtained at 30°C, 40°C, 45°C and uncontrolled temperature respectively. Finally, at 12.5% TS (Figure 9) gas production is maximum (13.551 litres) at 35°C, which is 1.98 times, 6.06 times, 24.9 times and 2.72 times higher than those obtained at 30°C, 40°C, 45°C and uncontrolled temperature respectively. From all these results, it can be concluded that gas production is more at 35°C with 8% TS. This large amount of biogas production at controlled temperature of 35°C digester is probably due to large microbacterial activity in the mesophyllic temperature range (Mahanta et al

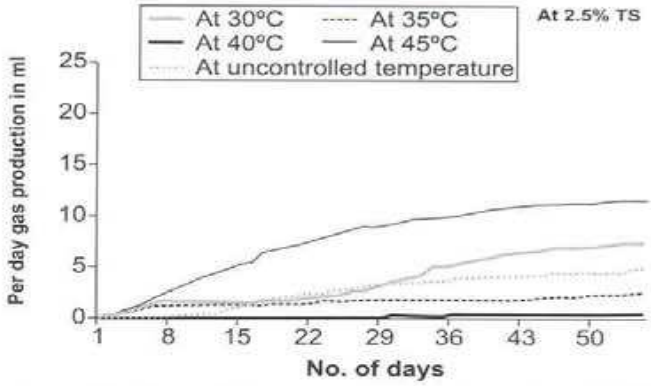


Figure 7: Cumulative gas production at 2.5% TS

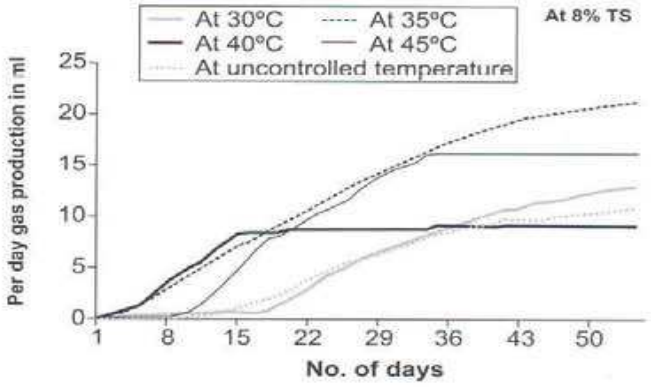


Figure 8: Cumulative gas production at 8 % TS

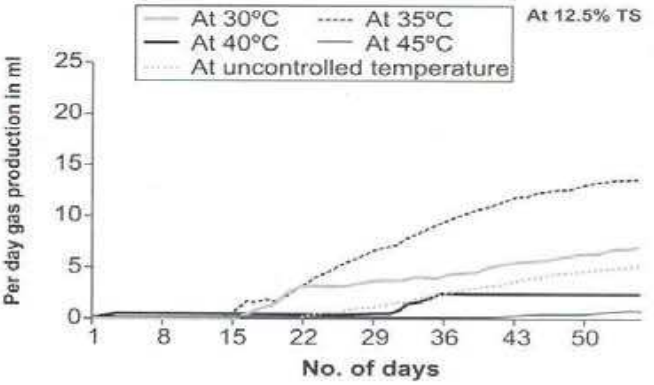


Figure 9: Cumulative gas production at 12.5% TS

2004). The corresponding temperature variation for all the three uncontrolled temperature digesters at 2.5% TS, 8% TS and 12.5% TS is shown in Figure10. From this figure, it is seen that all the plots

Table 2: Comparison of cumulative gas production

TS concentration	*Gas production in litres (in 55 days)*				
	30°C	*35°C*	*40°C*	*45°C*	*Uncontrolled*
Temperature					
2.5% TS	7.348	2.480	0.416	11.482	4.717
8% TS	13.011	21.395	9.110	16.150	7.238
12.5% TS	6.822	13.551	2.236	0.543	4.968

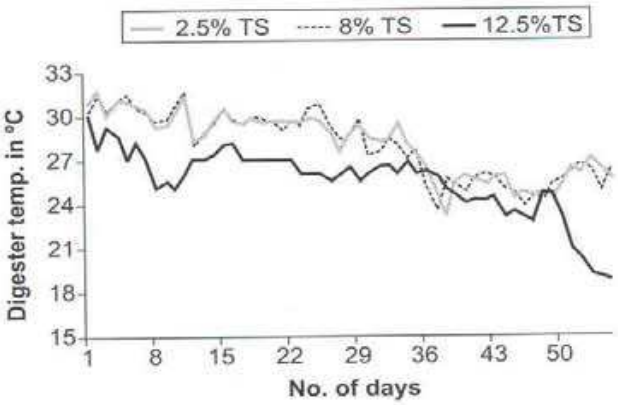


Figure 10: Comparison of digester temperature

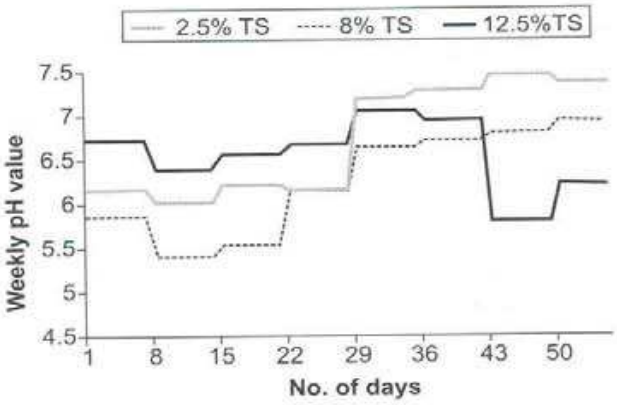


Figure 11: Comparison of pH value

are similar in nature showing a decrease of digester temperature with retention time, thereby showing a decrease in gas production in all cases. From the foregoing discussions, it can be interpreted that the effect of temperature is significant on biogas production rate.

Figure 11 shows the comparison of variation of weekly pH value at 2.5% TS, 8% TS and 12.5% TS. For all the total solid concentrations, the initial pH value falls in the acidic range, i.e. between 5.6 and 6.8, which increases to 7 in the fourth week where gas production is maximum (Wise 1987). This is a favourable condition for the gas production since the growth of methanogens is high in the range of 7.0 to 7.3 as reported (Wise 1987; Mittal 1996; Augenstein et al 1976).

Conclusions

The overall process of anaerobic digestion occurs through the symbiotic action of a complex consortium of bacteria. For efficient performance of a biogas plant, it is therefore necessary to regulate the factors that affect bacterial activity. Temperature and pH values of digester contents are also to be maintained within the desired range. Furthermore, a controlled temperature environment is essential for higher rate of biogas production. Similarly, the loading rate of feedstock and the withdrawal rate of digester slurry should also be properly balanced and continuously monitored. In the present investigation, the effect of temperature and total solid concentration on the performance of biogas digesters has been studied from the laboratory experiments.

Experiments were carried out with four different total solid concentrations and the temperature was varied from 30°C to 45°C in steps of 5°C. The gas production rate has been studied for a period of 55 days. The investigation undertaken shows a maximum of gas production at 35°C with 8% TS.

From the above study, it can be interpreted that temperature plays an important role for an efficient gas production rate. The present experimental findings would be extremely useful in selecting an optimum temperature environment and solid concentration of the feed material for higher rate of biogas production. Moreover, a high performance biogas digester can be designed and developed for the rural sector, where cattle-dung is found in abundance. The production and use of gaseous fuel from biomass through biomethanation could bring a major economic and environmental change to the rural sector.

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References

Aburas, R, Hammad, M & Abu-Reesh, I. 1995. Construction and operation of a demonstration biogas plant, problems and prospects, *Bioresource Technology*, Vol. 53, pp.101-104.

Augenstein, D C, Wise, D L, Wentworth, R L & Cooney, C L. 1976. Fuel Gas Recovery from Controlled Land Fill of Municipal Wastes. *Resources Recovery Conserve*, Vol. 2, pp.103.

Bushwell, A M & Hatfield, W D. 1996. Anaerobic fermentations, *Bulletin 3 Urbana*, IL: State of Illinois, Department of Registration and Education, USA.

Chowdhury, R. 1987. Kinetic study of anaerobic digestion, comparing the performances of batch and semi-continuous systems. *M. Phil. Thesis*, University of Reading.

Khandelwal, K C & Mahdi, S S. 1986. *Biogas Technology*. Vol.1, Tata McGraw-Hill, New Delhi.

Lopez, M, Montalvo, S, Freyges, A, Ruiz, M & Correa, O. 1992. Behaviour of presolubilized sludge in anaerobic digestion. International Society of Environmental Biotechnology, Cuba.

Lusk, P, 1998. Methane recovery from animal manures:

The current opportunities casebook. National Renewable Energy Laboratory, Colorado, USA, pp.3-22.

Mahanta, P, Dewan, A, Saha, UK & Kalita, P. 2004. Effect of temperature and agitation on the performance of biogas digesters. In: *Proceedings of 2nd BSME-ASME International Conference on Thermal Engineering*, Dhaka, Vol. 2, pp.873-879.

Maramba, F D. 1978. Biogas and Waste Recycling. The Philippines Experiences, *Liberty Flour Mills Inc.*, Metro Manilla, Philippines.

Mittal, K M. 1996. *Biogas Systems – Principles and Applications*. Tata McGraw-Hill New, Delhi.

Qasim, S R & Stinehelfer, M. 1982. Effect of a bacterial culture product on biological kinetics. *Journal of Water Pollution Control Federation*, Vol. 54, pp. 255.

Qasim, S R, Warren, K & Udomsinrot, K., 1984. Methane gas production from anaerobic digestion of cattle manure. *Energy Sources*, Vol. 7 (4), pp.319-341.

Rahman, M H. 1996. A study on biogas technology in Bangladesh. In: *Proceedings of 22nd WEDC Conference*, New Delhi, India.

Rahman, H. 2002. A mathematical model for fixed dome type biogas plant. *Energy*, Vol. 27, pp.25-34.

Safly. 1990. Development and marketing of an innovative low temperature lagoon biogas digester system. In: *Proceedings of XIV Conference on energy from biomass and wastes*, Lake Buena Vista, FL.

Wise, D L. 1987. *Global Bioconversions*. Vol. IV, Florida: CRC Press.

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