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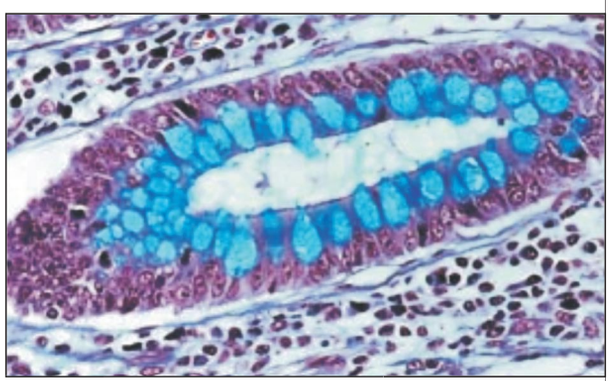

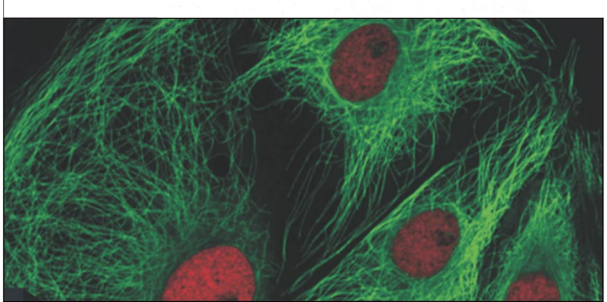

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Determination of minimum heat insulation thickness for an experimental methane fermentor

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Abstract. *The objective of this paper is to establish the minimum thickness of heat insulation for an experimental bioreactor, developed at the Institute of Microbiology of the Bulgarian Academy of Sciences, required to ensure heating of the fermentor with its own produced biogas. The experimental bioreactor is a cylinder of height h=935 mm and diameter d=435 mm. It has a water jacket around its shell to heat up the substrate. It is made in stainless steel of thickness 5 mm and of heat transfer coefficient =45 W/m.K. The fermentor is intended to be filled with substrate at 75-80 % of its volume. The bioreactor is designed with heat insulation in mineral wool of heat transfer coefficient =0.035 W/m.K. The biogas output of the bioreactor is 78 dm3 per 24 hours at energy value 6 kWh/m3. Heat loss of the fermentor is calculated using classical heat engineering equations. It is assumed that the substrate heated up in the bioreactor is a high inertia heat system which because of its large mass and not high temperature, will be exposed not to the impacts of the average day and night temperature, but to the monthly average. Results were obtained for the heat transfer coefficient and heat loss of the bioreactor (filled with cattle dung diluted in water) in mesophilic (35 °C) and thermophilic (55 °C) mode at different insulation thicknesses. Heat loss of the bioreactor in thermophilic operation mode is 57% higher than in mesophilic mode. The main conclusion from the research is that small bioreactors cannot ensure heating at their own using the produced biogas in wintertime. A highly efficient heat insulation of thickness of about 10 cm is advisable.*

Keywords: heat insulation, methane bioreactor, biogas, mesophilic and thermophilic modes.

Introduction

Anaerobic digestion (AD) is an effective biotechnological process for treatment of different agricultural, municipal and industrial wastes (Ahring, 2003). It combines depollution of highly concentrated organic wastes (ecological aspect) with production of renewable energy – biogas, the main component of which is methane (energy aspect). AD is a very unstable process in regard to the biogas reactors operation. This is due to the complicated interactions between different microbial species as well as of the complex transformations of the organic matter affected by a variety of environmental factors (Gerardi, 2003).

One of the most important factors for AD is temperature (Simeonov, 2010). There are two major temperature levels for biogas production: mesophilic – of temperature 30÷40 °C maintained inside the methane bioreactor, and thermophilic - respectively 50÷55 °C (Dinev et.al., 2006; Kualih, 1986). Under the Bulgarian geographical conditions both temperature levels require heat insulation. The use of heat insulation results in minimization of heat loss (cooling) in the bioreactor. Thereby heat power required for compensation of heat loss in the fermentator is also minimized.

The objective of this research is to determine the minimum heat insulation thickness required for a particular fermentor that will ensure its heating by the use of own biogas produced.

Material and methods

The experimental methane bioreactor has been developed at the Institute of Microbiology of the Bulgarian Academy of Sciences. It is a cylinder of height h=935 mm and diameter d=435 mm. It has a water jacket around its shell to heat up the substrate. It is made in stainless steel of thickness 5 mm and heat transfer coefficient =45 W/m.K. The bioreactor is intended to be filled with substrate at 75-80 % of its volume. As steel has high heat transfer characteristics, it can be considered that the walls of the biogas (upper) portion of the fermentor will have nearly the same temperature as the lower portion filled with substrate.

The bioreactor is designed with heat insulation in mineral wool of heat transfer coefficient =0.035 W/m.K. The biogas output of the fermentor is 78 dm3 per 24 hours at energy value 6 kWh/m3 (Ahring, 2003; Stamov et.al., 1986).

Heat loss of the fermentor is determined as follows (Stamov et.al., 1986):

- at the shell

$$Q_s = \frac{\pi}{\frac{1}{\alpha_1 d_1} + \frac{1}{2\lambda} h \frac{d_2}{d_1} + \frac{1}{\alpha_2 d_2}} h(Tf_1 \quad Tf_2), W \qquad (1)$$

- at the upper and lower end

$$Q_e = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_{u3}}{\lambda_{u3}} + \frac{1}{\alpha_2}} \pi \frac{d_1^2}{4} (Tf_1 \quad Tf_2), W \qquad (2)$$

$$Q_f = Q_s + 2Q_e, W$$

where:

α_1 and α_2 – heat transfer coefficient, respectively from substrate to the fermentor walls, and from the external walls to the

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environment, W/m2 °C

d_1 – internal diameter of fermentor, m

d_2 – external diameter of heat insulated fermentor, m

h – height of fermentor, m

Tf_1 – temperature of substrate inside fermentor, °C

Tf_2 – environmental temperature, °C

C_s – heat transfer coefficient of shell, W/m.K

C_e – heat transfer coefficient of lower and upper ends, W/m^{2}K

Q_f, Q_s, Q_e – heat loss, respectively of fermentor, its shell, and end, W

Heat resistance of the metallic casing is neglected because of its high heat transfer and insignificant thickness as compared to heat insulation. It is assumed that the substrate heated up in the fermentor is a high inertia heat system which because of its large mass and not high temperature, will be exposed not to the impacts of the average day and night temperature, but to the monthly average (Gerardi, 2003). Being the coldest month, January monthly average temperature for Sofia region is (– 0.4 °C) (Regulation № 7, 2004).

Heat power obtained from the biogas production of the fermentor (also at combustion in a gas boiler) is determined from the quotation (Simeonov , 2010).

$$Q_b = \frac{V_{dnb} q_b}{24.3600} \eta, W \qquad (3)$$

where Vdnb – day and night volume of biogas output, m3/24 h

qb – energy value of 1 m3 biogas, kWh/m3

η- boiler efficiency.

Results

Results were obtained for the heat transfer coefficient and heat loss of the bioreactor (filled with cattle dung diluted into water) in mesophilic (35°C) and thermophilic (55°C) mode at different insulation thicknesses (Table 1 and Figure 1)

Table 1. Values of heat loss in the methane fermentor as a function of insulation thickness.

	δ, cm	1	2	3	4	5	6	7	8	9	10
	C_e, W/m^2.K	2.77	1.64	1.16	0.90	0.73	0.62	0.54	0.47	0.42	0.38
	C_s, W/m.K	4.70	2.61	1.83	1.42	1.17	1.00	0.88	0.78	0.71	0.65
mesophilic	Q_s, W	155.6	86.4	60.6	47.0	38.7	33.1	29.1	25.8	23.5	21.5
	Q_e, W	29.1	17.2	12.2	9.4	7.7	6.5	5.7	4.9	4.4	4.0
	Q_f, W	184.7	103.6	72.8	56.4	46.4	39.6	34.8	30.7	27.9	25.5
thermophilic	Q_s, W	243.5	135.2	94.8	73.6	60.6	51.8	45.6	40.4	36.8	33.7
	Q_e, W	45.7	27.1	19.1	14.8	12.0	10.2	8.9	7.7	6.9	6.3
	Q_f, W	289.2	162.3	113.9	88.4	72.6	62.0	54.5	48.1	43.7	4.00

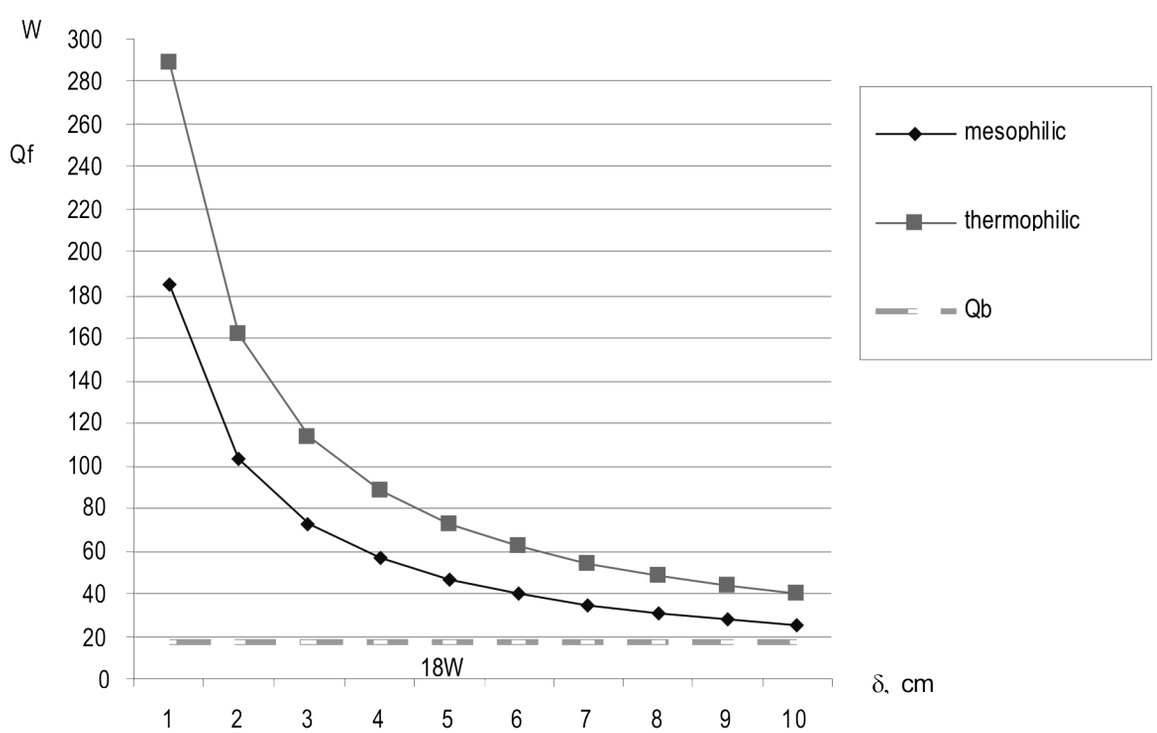

Figure 1. Variation in heat loss in the methane fermentor as a function of insulation thickness.

Values of the heat transfer coefficient at the ends of the bioreactor ce decrease from 2.77 W/m2K to 0.38 W/m2K at increase on insulation thickness from 1 cm to 10 cm. The similar heat loss of bioreactors end decreases from 29,1W to 4,0 W in mesophilic operation mode and from 45,7 W to 6,3 W in thermophilic operation mode. At similar change of insulation thickness the heat transfer coefficient at the shell cs decreases from 4.7 W/m.K to 0.65 W/m.K and the similar head loss Qs decreases from 155,6 W to 21,5 W in mesophilic operation mode and from 243,5 W to 33,7 W in thermofilic operation mode. The heat power from combustion of biogas production calculated by education (Simeonov, 2010) amounts to 18 W.

Summary heat loss of the bioreactor Qf decreases from 184,7 W (δ=1 cm) to 25,5 W (δ=10 cm) in the mesophilic operation mode and from 289,2 W to 40,0 W in thermofilic operation mode. Heat loss of the bioreactor in thermophilic operation mode is 57 % higher than in mesophilic operation mode.

Conclusion

In practice, small fermentors (up to 1 m^3) cannot ensure heating at their own using the produced biogas in wintertime. The obtained thickness of heat insulation is unacceptably high. A highly efficient heat insulation of thickness of about 10 cm is advisable and so part of the heat from the biogas produced will compensate for the heat loss incurred. For the climatic conditions of Bulgaria it is advisable to operate the fermentor in the mesophilic mode. Use in the thermophilic mode results in an increase of heat loss of the fermentor by 57 % and the increased biogas production can hardly compensate for it. The presented methane bioreactor will be used for optimization of biogas production from farming wastes (cattle and swine dung, chicken litter) and wastes from agro industry.

Acknowledgements

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