APPLICATION OF MATHEMATICAL MODELS TO OPTIMIZATION OF THE METHANE FERMENTATION OF FOWL DUNG

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Introduction

We applied mathematical modeling to the optimization of the methane fermentation of dung obtained from the breeding of farm animals in preceding research we carried out/Baykov, 1987, Baykov & Tyravska, 1991/. In the last few years compost is of greater interest as a resource for increasing soil fertility. The conducted research /Baykov, 1987/ indicates that the compost, obtained from the methane fermentation of fowl dung, is a source of biogenic chemical elements in optimal proportions. In the Ordinance for the organic production of plants /Ordinance №22/2001 of the Ministry of Agriculture and Forestry/ it is stated that the manure that can be used is produced from just a few farms. These are the reasons to carry out a research on optimizing the methane fermentation for a little farm, breeding 5000 laying hens without any litter, by applying mathematical modeling.

Material and methods

The quantity of dung from the 5000 laying hens' farm, bred in cage batteries, and the quantity of the dry substance and the organic substance of the dung are studied by the methods described by Baykov /1987/. The methane fermentation is realized in a microprocessor controlled laboratory fermentor and the mathematical modeling is carried out using the algorithm described by Baykov & Tyravska/1991/.

Results

We used the model of Chen and Hashimoto/1978/ for optimizing the methane fermentation. This model was used by many authors when working with laboratory, pilot and industrial biogas installations. It was applied to a wide range of values of the variables as well as for different kind of substrates /Chen & Varel, 1980/. In their research we didn't find data on optimizing the methane fermentation of dung from laying hens that was why we applied their model to this kind of substrate, obtained from a 5000-birds farm. The equation describing the technological methane output i.e. the methane output per unit of fermentor volume per day is the following:

$$Y_V = \frac{B_0.S_0}{\theta}(1 - \frac{K}{\mu m 0 - 1 + K})$$

Y_V - technological methane output – dm^3 CH_4/dm^3 fermentor

B_0 – maximum methane output per unit of organic matter in the substrate - dm^3 CH_4/gV_s

S_0 – concentration of the organic matter of the substrate - $gV_s/$ dm^3

θ – period of exchange – days

K – Kinetic constant

μm - maximum specific growth rate of the microorganism population – day^{-1}

According to the model, the technological methane output for given values of S_0 and θ is determined by the specific characteristics of biodegradation of the substrate and the kinetic constants μm and K. The physicochemical parameters which have an impact on them are: for B_0 - the kind of the substrate; for μm – the temperature of the process; for K – the concentration of the organic matter in the substrate.

For this model the kinetic constant K represents the different types of inhibition of the process and it depends absolutely on the chemical characteristics of the substrate.

The analysis of the model shows that for constant values of: the period of exchange/ θ/, the temperature of the process and the chemical characteristics of the substrate - the value of K is a function of the concentration of the substrate. The increase of the concentration above a certain value leads to an inhibition of a different kind and to a decrease of the methane output.

On the basis of the models of Chen and Hashimoto /1978/ and Chen & Varel /1980/ and by using the described kinetic relations, we developed a modified form of the model and a program for optimization analysis. The equation is the following:

$$P = B_0.2{,}6.10^3(1 - \frac{K}{\mu m\theta - 1 + K})$$

$$Y_V = (\frac{P}{2{,}6.10^3}).(\frac{S_0}{\theta})$$

$$V = \theta.\frac{2{,}6.10^3}{S_0}$$

$$Q = B_0.2.10^2(1 - \frac{K}{\mu m\theta - 1 + K})$$

The symbols are the same like in the described model only the following are:

P – Total methane output from the fermentor processing dung

V – Volume of the fermentor

Q – Degree of degradation of organic matter/%/

Table 1 Values used in the mathematical model for the optimization of the methane fermentation of dung from laying hens bred in cage batteries

Parameters	Units	Quantity
Quantity of dung	kg/day	533
Dry substance– TS	kg/day	106
Volatile organic substance – VS	kg/day	87

The modified form of the model, where we applied a program for optimization analysis, gives the opportunity to determine: 1) the total methane output – dm^3 CH_4/day, 2) the technological methane output - dm^3 CH_4/ dm^3/day, 3) the degree of degradation of organic matter in the substrate /%/, 4) the volume of the reactor in m^3, at different values of the variables in the technological regime regarding a 5000 bird farm. The computer analysis program gives the opportunity to optimize the design of the installation and to develop an optimal technological regime.

In the program the following values of the technological variables are set:

B_0 – open

T – from 20^0 to 60^0C at 1^0C transition

S_0 – from 20 to 80 gV_s/dm^3 at 1 gV_s/dm^3 transition

θ – from 3 to 35 days at 1 day transition

Data for the quantity of dung and its quality indices, presented in Table 1, are obtained by a physicochemical study on the dung from birds bred in cage batteries.

We accept the following as optimization criteria: 1) the maximum mineralization of the organic substances in the substrate/ ecological criterion –P criterion/; 2) total maximum gas output or maximum technological methane output/economic criterion - Y_V criterion/. The optimal values of S_0, T and θ are these values for which their increase with 1 gV_s/dm^3, 1^0C and 1 day leads to the increase of the efficiency of the process with at least 1%.

The results from the optimization analysis are presented in table 2.

Table2 Results from the optimization analysis

Parameter	Units	Criteria	
		P	Y_V
Temperature – T	^0C	33	55
Period of exchange – θ	days	15	6
Substrate concentration – S_0	gVS/1	39	45
Loading	gVS/day	2,6	9,0
Working volume – V	m^3	32,5	9,7
Total methane output – P	m^3/day	21,4	15,5
Technological methane output - Y_V	1 CH_4/day	0,65	1,6
Degree of degradation – Q	%	49,27	32,76

Discussion

The analysis of the model indicates that, for concentration of the organic matter in the substrate from 20 to 60 gV_s/dm^3, maximum efficiency by the Y_V criterion is achieved at 5-8 days period of exchange, whereas maximum total output is achieved for twice as long a period of stay of the substrate in the fermentor. For a given value of S_0 and T above 35^0C, the period of exchange is the basic parameter of the process which influences the degree of degradation of the substrate. The longer period of exchange is good for the ecological efficiency of the process in a technological regime optimized by the Q criterion. As our research indicates, the longer the stay in the fermentor, the higher the decontamination effect assessed by the presence of pathogenic and sanitary index microorganisms. At longer methane fermentation the organic matter is more thoroughly mineralized and the dry rest from the fermentation process consists of stabilized slime with very good qualities for increasing soil fertility.

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