

Energy efficiency of food production wastewater anaerobic-aerobic treatment

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Abstract. The advanced energy- and resource saving technologies of food production wastewater treatment include anaerobic and aerobic steps. At present, various methods of intensification and optimization are used to increase the efficiency of anaerobic processes of wastewater treatment, including selection of active microbial communities, providing the optimum temperature regime, immobilizing biomass by granulation or biofilm formation, reducing various inhibitory effects, phase separation or pre-acidification, chemical or biological pretreatment of wastewater. The aim of this investigation was researching the effect of hydraulic and organic load rates on the energy efficiency of the wastewater treatment process and evaluating the energy efficiency depending on process conditions. Experimental laboratory installation included subsequently connected bioreactors, one from which acted as first stage and other bioreactors - as the second stages of anaerobic process. It was shown that the biogas formation at the first and second stages differs significantly. A small volume of released biogas on the first stage allows us to ignore it, but characteristics of biogas formation at the second stage bioreactors are close and are described by general functional dependence. The specific yield of biogas from the organic matter consumed Y_{bg} is independent of the specific organic load rate L , but is dependent on the specific flow rate of the treated water D .

1 Introduction

At present, various methods of intensification and optimization are used to increase the efficiency of anaerobic processes of liquid waste and wastewater treatment. Among these methods are formation of microbial communities with high enzymatic activity, specific microbe composition corresponding to substrate utilized and thermal sensitivity [1], providing the optimum temperature range [2-4], immobilizing the biomass by granulation or biofilm formation [5-7], reducing inhibitory effect of various origin [7-9], spatial phase separation or preacidification [2, 10-11], pretreatment of wastes with chemical methods (acid or alkaline hydrolysis, oxidants) or biological ones (fermentation agents or microbial enzymes) [12-15].

However, in order to obtain the desired effect it is necessary to provide correct stages volumes ratio due to the difference in the growth rates of the anaerobic bacteria groups. Solving this issue requires preliminary laboratory modeling of the treatment process followed by it mathematical optimization.

Earlier, the possibility of optimizing the process of combined anaerobic-aerobic treatment of wastewater of the milk processing plant using the treatment efficiency criterion was shown [11]. Another possible optimization criterion is the energy efficiency of the process.

In this connection, the objectives of the present study were:

1. Research of the effect of hydraulic and organic load rate on the energy efficiency of the wastewater treatment process.
2. Evaluation of the process energy efficiency depending on process conditions.

Key control parameters determining microbial metabolism in continuous culture are the flow rate of the medium (i.e. treated wastewater) as well as the total concentration of organic matter therein. The derived values are the specific flow rate of the treated water D and the specific organic load rate L [11].

Since successive stages of anaerobic methanogenic process are characterized by different composition and physiological features of microbial communities, optimal conditions of their activity is achieved by spatial separation of stages.

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2 Methods

Experiments were carried out at a laboratory installation consisting of subsequently connected bioreactors (Figure 1).

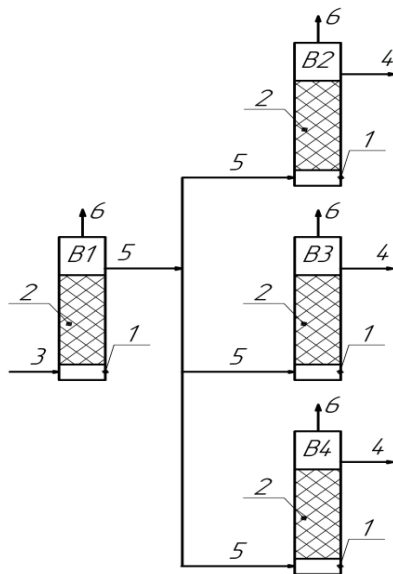


Fig. 1. Schematic design of the experimental wastewater treatment installation: 1-bioreactors, 2-packing material with immobilized biomass, 3-inlet wastewater pipe, 4-outlet treated wastewater pipes, 5-overflow pipes, 6-biogas bleeding pipe

Bioreactor B₁ acted as the first stage of anaerobic treatment, B₂-B₄ - bioreactors of the second stage of anaerobic methanogenic process. Volumes of bioreactors of the second stage B₂, B₃ and B₄ differ and, accordingly, ratios of the first and second stages volumes varied (Table 1).

Table 1. Laboratory wastewater treatment installation characteristics

Parameter	Unit of measure	Bioreactors			
		B ₁	B ₂	B ₃	B ₄
Bioreactor volumes V	l	2.64	2.00	1.52	0.74
1st / 2nd stage volumes ratio	-	-	1.3	1.7	3.6

Volume flow rate of treated wastewater G was varied from 83.5 to 226 ml·h⁻¹. The daily volume of biogas V_{bg}, ml·day⁻¹, was measured by a volumetric method, and the content of organic matter S, g COD·l⁻¹, by a standard test

Table 4. Calculated specific organic load rate L, g COD·l⁻¹·day⁻¹

Bioreactors			
B ₁	B ₂	B ₃	B ₄
2.4±0.2	0.2±0.04	0.2±0.04	0.1±0.01
2.9±0.3	0.5±0.1	0.7±0.05	1.5±0.2
5.2±0.4	1.1±0.1	1.4±0.16	3.0±0.4
7.6±0.5	1.7±0.2	2.2±0.2	4.5±0.4
10.7±0.8	1.8±0.2	2.4±0.2	4.8±0.4

method based on the dichromate reduction [16], separately for all bioreactors.

The wastewater specific flow rate D, day⁻¹, specific organic load rate L, g COD·l⁻¹·day⁻¹, specific organic matter destruction rate P, g COD·l⁻¹·day⁻¹, specific biogas formation rate Q_{bg}, day⁻¹, and specific biogas yield of organic matter consumed Y_{bg}, l·g COD⁻¹, were calculated in accordance with equations 1-5 [11, 17]:

$$D=G/V \quad (1)$$

where G is volume flow rate of wastewater, l·day⁻¹, V – bioreactor volume, l;

$$L=S_{in} \cdot D \quad (2)$$

where S_{in} is the organic matter content of the wastewater, g COD · l⁻¹;

$$P=(S_{in}-S_{out}) \cdot D \quad (3)$$

where S_{in} and S_{out} are the organic matter inlet and outlet contents of all bioreactors;

$$Q_{bg}=V_{bg}/V \quad (4)$$

$$Y_{bg}=Q_{bg}/P \quad (5)$$

3 Results and discussion

Measured values of wastewater volume flow rate in all bioreactors are given in Table 2, and organic matter concentrations at the inlet to the installation and at the bioreactors outlets - in Table 3.

Table 2. Volume flow rate of wastewater in bioreactors G₁-G₄, ml · h⁻¹

Bioreactors			
B ₁	B ₂	B ₃	B ₄
83.5±1.1	27.9±1.1	27.8±1.4	27.7±1.6
113.0±1.4	37.7±1.3	37.7±1.7	37.7±0.9
156.0±1.8	52.3±0.9	51.7±2.0	52.0±1.1
226.0±2.8	75.3±2.4	75.3±1.1	75.3±2.1
283.0±3.4	94.3±3.8	94.3±2.9	94.3±3.6

Table 3. Organic matter concentrations S_{in} and S_{out}, g COD·l⁻¹

Inlet	Bioreactors outlets			
	B ₁	B ₂	B ₃	B ₄
3178.0±311	726.0±70	381.4±32	149.8±11	111.5±11
2894.0±233	1254.5±111	213.6±24	104.9±10	127.9±15
3680.0±375	1783.0±166	45.7±3.8	60.1±5.1	144.2±13
3744.0±369	1872.0±190	146.0±15	79.0±7.1	163.0±18
4180.0±398	1581.0±144	100.5±11	166.0±13	124.0±11

The L and P values calculated according to the equations 2 and 3 for all bioreactors are shown in Tables 4 and 5.

Table 5. Calculated specific organics matter destruction rate P , $\text{g COD}\cdot\text{l}^{-1}\cdot\text{day}^{-1}$

Bioreactors			
B ₁	B ₂	B ₃	B ₄
4.9±0.4	0.2±0.03	0.2±0.02	0.2±0.01
4.4±0.4	0.9±0.1	0.5±0.06	0.5±0.04
7.1±0.9	2.2±0.2	1.2±0.1	1.2±0.1
10.2±1.0	3.1±0.3	2.0±0.2	1.9±0.2
17.7±1.8	3.4±0.3	2.1±0.2	2.1±0.2

Daily biogas volumes V_{bg} , $\text{ml}\cdot\text{day}^{-1}$, depending on specific organic load rate L , $\text{g COD}\cdot\text{l}^{-1}\cdot\text{day}^{-1}$, are shown at Figure 2.

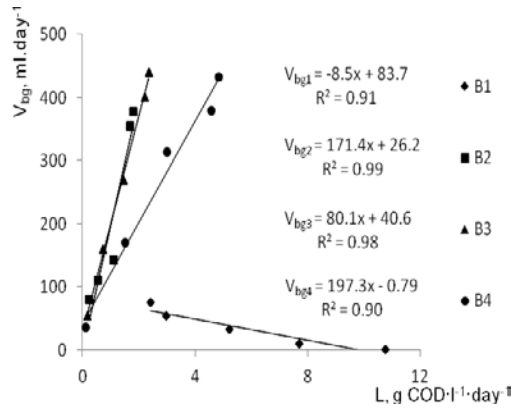


Fig.2. Daily biogas volumes V_{bg} vs specific organic load rate L

It can be seen from Fig.2 that the daily volume of biogas at the first stage of anaerobic stage (bioreactor B₁) differs significantly from similar values at the second stages B₂-B₄ both in absolute value (it does not exceed 100 ml per day) and in the dependence on the L . In other words, the formation of biogas at the first stage is small in all studied modes.

On the other hand, the dependence of biogas formation on organic load is close at all second stages. This can be explained by the fact that these stages are supplied from the first bioreactor B₁ by the liquid of identical chemical composition, so they are under close conditions by hydraulic and organic load. These dependencies are quite well ($R^2=0.67$) described by a common function (Fig.3).

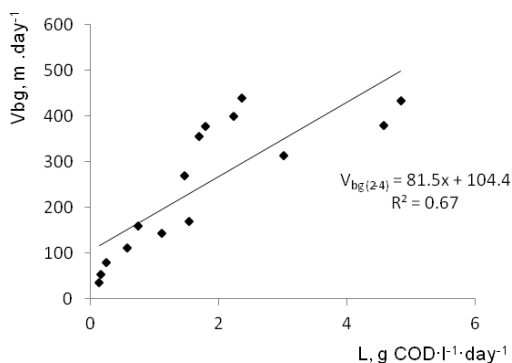


Fig.3. Daily volume of biogas V_{bg} in bioreactors B₂-B₄ (generalized) vs specific organic load rate L

It was interesting to determine the specific biogas yield of organic matter consumed Y_{bg} vs specific organic

load rate L . These relationships for individual second stage bioreactors B₂-B₄ are shown in Figure 4.

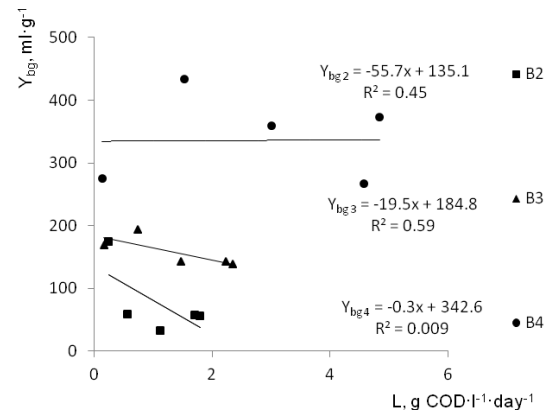


Fig.4. Specific biogas yield of organic matter consumed Y_{bg} in bioreactors of the second stage

As can be seen from the Figure 4, the specific biogas yield Y_{bg} varies slightly with the change of L , as evidenced by the low values of approximation reliability (respectively 0.009, 0.59 and 0.45). This indicates the stoichiometric nature of this parameter [17], i.e. the specific biogas yield Y_{bg} is determined mainly by the chemical composition of the consumed matter and is independent of the specific organic load rate L .

However, there is a difference in Y_{bg} at different D values for the second stage reactors B₂-B₄. The biggest Y_{bg} value equal to $0.34 \text{ l}\cdot\text{g COD}^{-1}$ is observed at the bioreactor B₄ functioning at the highest specific flow rate D , equal 0.54 day^{-1} . At lower volume ratios and specific flow rate (B₂ and B₃ bioreactors) Y_{bg} values are significantly lower, 0.185 and $0.135 \text{ l}\cdot\text{g COD}^{-1}$, respectively.

The obtained experimental data and their correlations make it possible to develop an optimization algorithm for the milk processing wastewater treatment.

Conclusions

1. The biogas formation at the first and second stages of the anaerobic stage differs significantly in character and absolute values. A small volume of released biogas allows us to ignore it.
2. The characteristics of biogas formation in second stage bioreactors are quite close and are described by general functional dependence.
3. The specific biogas yield of organic matter consumed Y_{bg} is independent of the specific organic load rate L , but substantially dependent on the specific flow rate D .

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