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Optimization of the process of anaerobic-aerobic purification of waste waters of food production using the spatial separation of stages

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Abstract. The advanced energy- and resource saving technologies for purification of industrial waste waters from the food production include both anaerobic biotechnologies, and the combined ones, which include anaerobic and aerobic purification steps. They possess such advantages as economic efficiency, high purification efficiency, minimal formation of excess sludge and ability to obtain alternative energy carrier - biogas. The aim of this investigation was to perform optimization of the process of anaerobic-aerobic biological purification of wastewaters from the milk treatment enterprise. During our investigation we have studied relations between the efficiency of the process of anaerobic-aerobic biological purification of wastewaters of the milk treatment enterprise and specific organic load. We investigated influence of the spatial separation of the anaerobic step of purification with directed succession of the microbial community, which performs the sequence of destruction of the organic compound on the process efficiency. It was shown, that the preliminary anaerobic purification of wastewaters from the milk treatment enterprise allows one to significantly reduce organic load at the aerobic stage of the purification facilities and remove up to 85% of the organic compound. With increase of the specific organic load from 1.4 up to 2.8 kg COD·m -3·days-1 we see a drastic improvement of the efficiency characteristics both for anaerobic and aerobic stages. The redox-potential of the fermentation medium depends on the metabolitic activity of the microbial community and might be used as an efficiency characteristics for destruction of the organic compound at the anaerobic stage, and as an indicator for the oxygen saturation of the medium at the aerobic stage of purification.

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1 Introduction

Nowadays in order to improve efficiency of the anaerobic processes of the liquid waste processing and wastewater purification one uses various methods for intensification and optimization of the processes.

The method for the microbial community formation is based on complex and multi-stage character of the microbial biodestruction processes of the complex organic substrates. Directed formation of these communities and providing optimum conditions for its metabolism allows one to increase and balance its metabolic activities, and avoid the processes' limiting in the "bottle-necks". At this the microbial content of the community, its substrate specificity and thermosensibility vary a lot depending on the selection conditions [1].

The temperature of anaerobic process is one of the key factors, which denote the growth rate for the microbial population and its destruction activity. So, while comparing the efficiency of anaerobic biofilters, which purify wastewaters of the milk-treatment enterprise at three temperatures (12.5°C, 21°C and 30°C), the temperature of 30°C has shown more advantages over other temperatures when concerning the time for achievement the highest purification efficiency, and purification efficiency at the same hydraulic modes. Biogas output from the consumed substrate was less for the low temperatures. However, the methane content in biogas was higher.

The thermophilic mode provides high rates of the organic substance destruction at significant energy expenses, so mesofilic ans submesofilic conditions (15-45°C) have gained widespread usage. They provide acceptable purification rates and high stability of the process due to the wide species content of the mesofilic microorganisms [3]. Nevertheless the mode selection should be performed basing on the specific expenses per a unit of volume of the purified water.

Granulation. Formation of the granulated biomass is a unique phenomenon of self-organization of the methanogenic microbial community. Besides the UASB-reactors, formation of granules is observed only in the reactors with suspended-sedimentating biomass (hybrid, septate, anaerobic biofilter with an upward flow, reactor with a fluidized-bed sludge) [4-8].

As the anaerobic microorganisms are rather sensitive to the toxicants and inhibitors behaviors, searching for the ways for reduction of the inhibitor impact is of immediate interest [9-11].

Separation of the anaerobic process phases is used for intensification of the methanogenic fermentation in a continuous mode during the effluents treatment even for rather simple contaminations (carbons etc.). However, they appear to be more useful at purification of wastewaters with more complicated contaminations, including proteins, amino acids, fats [2]. Technologically the methane fermentation process is divided into 2 stages [12]: Hydrolysis of biopolymers, formation of lower fatty acids and its conversion into acetate, hydrogen and carbon dioxide (acidogenic stage) and the methane fermentation itself (methanogenic stage). The conception of the two-stage fermentation of organic wastes in the hybrid bioreactors, presented in the works of Yang and co-authors [13], is based on the usage of the first stage in the total-mixing mode for performing hydrolysis, acido- and acetogenesis. Whereas the function of the second stage (without intermixing) is methanogenesis and solid phase precipitation.

For providing the correct relation between the stages volumes, which appears due to the difference between the growth rates of the two bacteria types, one needs a preliminary laboratory modeling aiming at obtaining the correlation dependences with further mathematical optimization of the process.

The preliminary waste treatment is used for speeding-up the destruction of the substrates being degraded, for example, fats, proteins, lignicellulosic wastes. Low profitability of the chemical ways of pretreatment is denoted by formation of inhibitors, necessity for detoxication of the fermentation medium before the methanogenesis, high consumption of heat energy, low output of the desired substrate. Nevertheless, the preliminary thermo-alkali treatment of the excess sludge before the methanogenic fermentation allowed one to increase the efficiency in regards to biogas for 34.3%, and the destruction degree of the organic compound for 67.8%.

Biological methods of the preliminary treatment are based on usage of the fermental specimen or microorganisms, which secrete the ferments [15-17].

2 Laboratory modeling of the anaerobic-aerobic purification of wastewaters from food production

We have estimated technological parameters of the anaerobic-aerobic purification of the milk-treatment enterprise wastewaters in the laboratory conditions. Our aims were the following:

1. To investigate the influence of the hydraulic and organic load on the technological characteristics of the process for biological purification of wastewaters.
2. To assess the efficiency of the microbial community, which provides anaerobic destruction of the organic compound at spatial separation of the anaerobic stage.

It is known, that specific flow rate D of the wastewater being purified and total concentration of the organic compounds S are the key parameters, which denote the microbial methabolism in continuous cultivation conditions. We have varied the initial total concentration of the contaminating substances S, kg COD·m -3, and volumetric flow rate of the liquid being purified G, m3·h-1.

The technological parameters: specific flow rate D, days-1, and specific organic load L, kg COD·m-3· days-1, were calculated using the formulas [18]:

$$D = \frac{G}{V_p} \tag{1}$$

where G is volumetric liquid consumption, dm3·days-1, Vp is the bioreactor volume, dm3.

$$L = Sin \cdot D, \tag{2}$$

where Sin is concentration of the organic compound in liquid, kg COD·m-3.

Efficiency of purification from the organic compounds E was estimated according to the formula:

$$E = \frac{S_{in} - S_{out}}{S_{in}} \cdot 100\% \tag{3}$$

The experiments were carried out using the sequential connection of four bioreactors A1-A4 (with phase separation) or two bioreactors A1 and A2 (without phase separation) with variation of the technological modes and its parameters, which are described in Table 1.

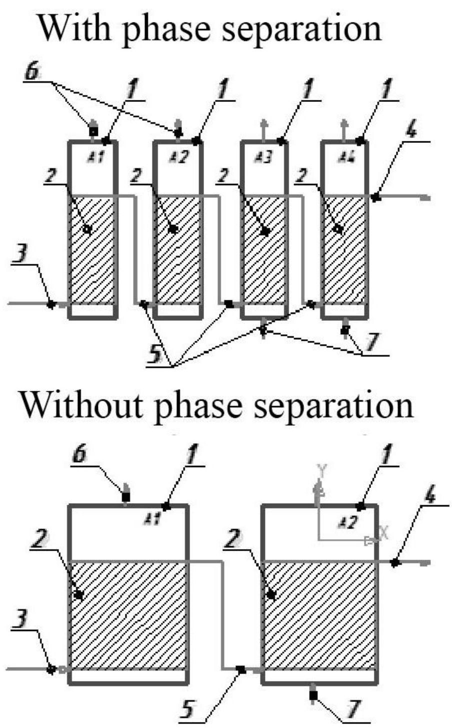

Fig. 1. Principle schemes for the bioreactors connection: 1 - bioreactors, 2 - load with immobilized biomass, 3 - inflow of the effluent water in the first bioreactor, 4 - outflow of the purified effluent water, 5 - overflow pipelines, 6 - biogas outflow, 7 - air for aeration of the aerobic stage

Table 1. Characteristics of the investigated modes

Short description of the mode	G	S	D	L
	$10^{-6} \cdot m^3 \cdot h^{-1}$	kg COD·m^{-3}	$days^{-1}$	kg COD· m^{-3} $days^{-1}$
1. Phase separation, low D	78.0±8.0	3.5±0.8	0.42±0.2	1.4±0.2
2. Phase separation, medium D	112.0±10.1	3.5±0.9	0.60±0.1	2.0±0.3
3. Phase separation, high D	149.0±15.1	3.8±0.9	0.84±0.1	3.0±0.4
4. Phase separation, low D, increased S	78.0±8.0	4.2±1.0	0.42±0.1	1.7±0.3
5. Phase separation, low D, double S	78.0±8.0	6.8±1.6	0.42±0.1	2.8±0.4
6. Without phase separation, low D	78.0±8.0	3.5±0.9	0.42±0.1	0.9±0.1
7. Without phase separation, high D	149.0±15.1	3.7±0.9	0.84±0.1	2.8±0.4

We carried out comparative study of the process at variation of the flow rate (modes 1,2,3), at variation of the specific organic load (modes 1, 4, 5), as well as with spatial separation of the phases of the anaerobic stage (modes 1 and 3) and without it (modes 6 and 7).

For the described modes we carried out the process up to the establishment of the steady-state conditions, which generally took about 12-16 days at temperatures from 22.0 to 26.0°C.

The obtained results are presented in Figure 2.

It is seen form the obtained data that at increasing of the medium flow D from 0.42 to 0.6 and further up to 0.84 days-1 (modes 1, 2, 3) there are practically no changes in overall efficiency of the unit operation, which is 98-99%. However, we observe some redistribution of efficiencies among the stages, and the load "moves" to the later aerobic stages of the process, where the destruction of the major part of contamination takes place.

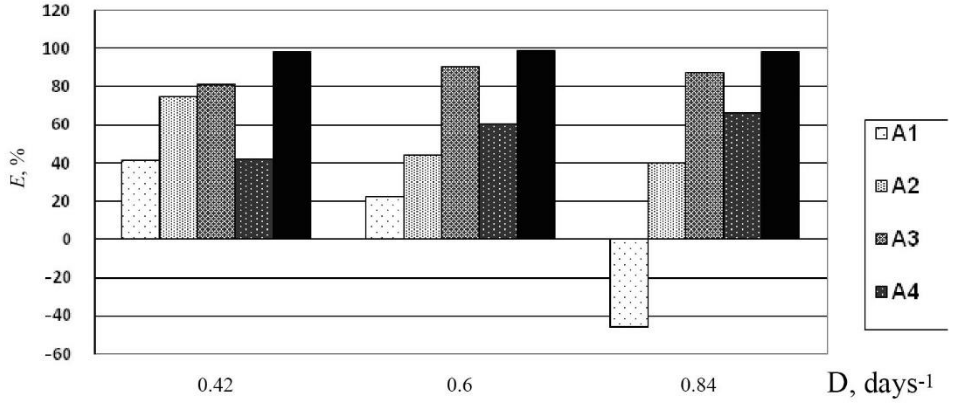

Fig. 2. Relation between the medium flow D and the purification efficiency E

For the investigated range the efficiency of the anaerobic stages operation decreases at increase of the flow rate of the wastewater being purified. When D excesses o.8 days-1 we even observed an increase of the total contamination and the purification efficiency E had a negative value, which might be explained by active accumulation of volatile fatty acids at the fermentation medium.

While examining the influence of the specific organic load L on the purification efficiency E (Fig.3) at equal medium flow D (modes 1, 4, 5) one may notice that for the 1st anaerobic stage of purification A1 the destruction efficiency of the organic compounds increases from 41 to 54% accompanied with insignificant increase of the efficiency of the second anaerobic stage A2 from 74 to 78%. The most noticeable growth of efficiency is observed at the final aerobic stage: from 40% to 84%.

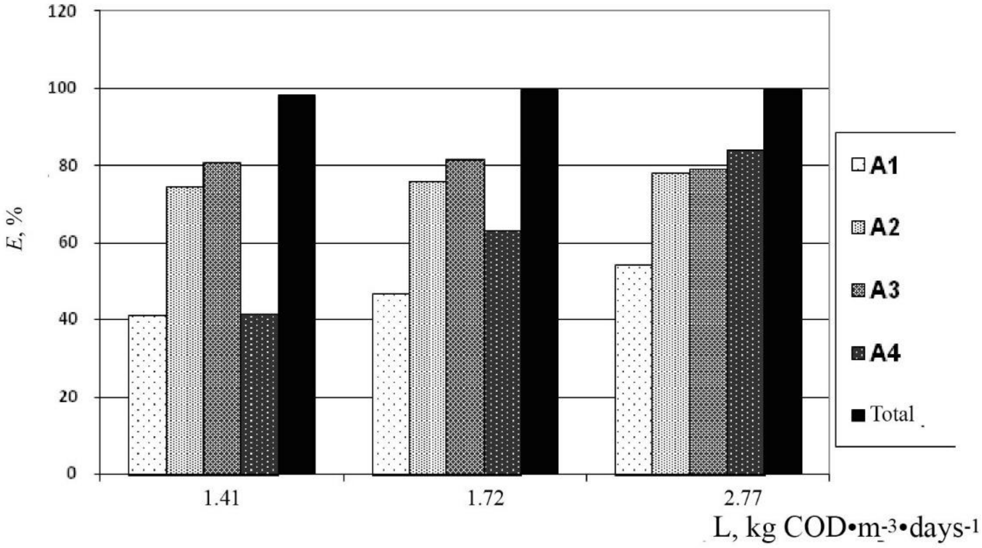

Fig. 3. Influence of the specific organic load L on the purification efficiency E

The total purification efficiency didn't change and was 98-99.6%. The experimental regularity is in a good agreement with the numerous literature data [11] concerning the efficiency of the anaerobic treatment of wastewater with high content of the easily digested organic compound.

Influence of spatial phase separation of the anaerobic stage of the process is presented in Figure 4.

Increasing of the flow rate for the mode with phase separation of the anaerobic stage (modes 1 and 3) resulted in reduction of purification efficiency at the first anaerobic stage of the process A1 and A2, which later was totally compensated at the 3 and 4 aerobic phases of purification.

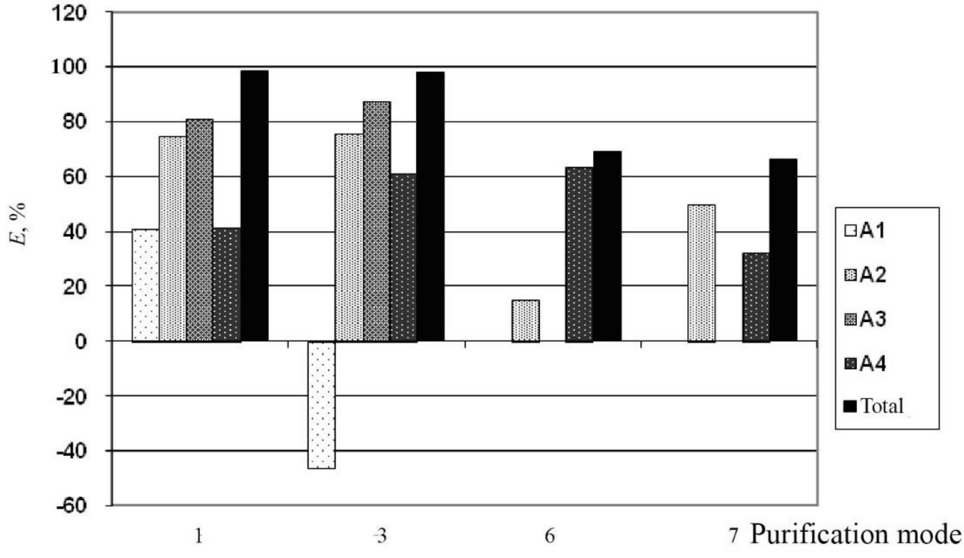

Fig. 4. Influence of the spatial phase separation of the anaerobic stage on the COD purification efficiency

Comparison of the characteristics of the biological treatment in the units with anaerobic stage separation into two phases (modes 1 and 3) with similar characteristics without such separation (modes 6 and 7) has shown, that at equal flow rates (modes 1 and 6, modes 3 and 7) purification efficiency for the units without phase separation was less both at anaerobic and aerobic stages separately, and for the unit as a whole (63-66% against 98-99%), which proves the fact for the process efficiency improvement at the spatial separation of the anaerobic biocenosis [19].

3 Influence of the technological parameters and physico-chemical properties of the medium on the efficiency of wastewater purification

Investigation of the physico-chemical characteristics of the fermentation medium (pH and E_h) depending on the process phase was of interest.

It is known that the rate and direction of conversion of the organic compound from wastewater by anaerobic organisms depend on the oxidising-reducing medium conditions, which are expressed using the redox-potential (ORP, Eh_7) [20]. For taking into account the relation between ORP and pH we used the normalized Eh_7 value at pH =7:

$$Eh_7 = Eh + 60 \cdot (7 - pH) \tag{4}$$

Eh_7 values for the fermentation medium at the sequential phases of the wastewater purification A_1-A_4 are presented in Table 2.

Table 2. ORP values of the fermentation medium depending on the process phases

Phase name	Eh_7, mV						
	Purification mode						
	1	2	3	4	5	6	7
A_1	-235	-185	-160	-255	-275	-180	-150
A_2	-340	-310	-280	-350	-360		
A_3	+120	+80	+110	+130	+130	+140	+120
A_4	+140	+110	+155	+160	+155		

Vital activity of the microaerophilic and facultative-anaerobic microflora at the initial stages of the organic compound destruction results in total depletion of oxygen and accumulation of the electrolyte reduced forms in the treated wastewaters. Separation of the anaerobic treatment stage on two phases is accompanied by creation of the more reduced medium conditions.

At the stage of the aerobic post-treatment the Eh_7 value increases up to +120 - +140 mV due to high content of O_2 in the medium (more than 6 $mg \cdot dm^{-3}$). However, this value doesn't reach maximum in the range +250 - +280 mV, which states for the high respiratory activity of the aerobic biocenose and, consequently, low content of O2. At increasing the medium flow rate D from 0.42 to 0.84 $days^{-1}$ (modes 1-3) we observe an increase of the Eh_7 value both at the first and at the second stages of the anaerobic stages, which is explained by decreasing of the medium recovery degree at reduction of the treatment time.

Analysis of the relation between Eh_7 of the process phases and the organic load L (modes 1, 4, 5) shows that the increased load intensifies the destruction of the organic compound and significantly reduces Eh_7 value at the first phase of the anaerobic stage. At the second phase of anaerobic stage these characteristics are almost equal.

Analysis of the influence of the spatial phase separation of the anaerobic stage of biodestruction (modes 1, 3, 6 and 7) shows that it has a contribution to the process differentiation at the expense of creation of various oxidising-reducing medium conditions at the first and second phases of the anaerobic stage of purification.

pH variations according to the process phases (Table 3) show that at low content of organic compound in wastewater (modes 1, 2, 3) at the first anaerobic stage pH reduces only for 1.0-2.2 units, which states for the presence of balance of the two processes: accumulation of fatty acids as a result of vital activity of the acidogenic microflora and its utilization by the methanogenic one.

Table 3. pH values of the fermentation medium depending on the process phases

Phase name	pH, units						
	Purification mode						
	1	2	3	4	5	6	7
Input	5.8±0.4	5.8±0.5	5.9±0.6	5.6±0.3	5.5±0.6	5.5±0.4	5.5±0.4
A_1	7.6±0.4	6.6±0.7	5.4±0.5	4.9±0.3	3.7±0.4	5.1±0.4	7.1±0.3
A_2	8.4±0.6	7.4±0.6	7.0±0.5	5.5±0.6	7.6±0.5		
A_3	8.9±0.6	7.5±0.4	8.1±0.6	8.0±0.4	8.1±0.4	6.7±0.4	8.1±0.4
A_4	8.8±0.7	7.9±0.3	8.4±0.7	8.3±0.6	8.3±0.3		

Increasing of the organic load (modes 1, 4, 5) results in misbalance between accumulation and consumption of fatty acids, i.e. growth of its' concentration in the fermentation medium and decrease of pH value. In the process without phase separation of the anaerobic and aerobic stages (modes 6 and 7) this tendency is not observed.

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