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ENVIRONMENTAL AND SECURITY ASPECTS WASTEWATER TREATMENT STATIONS OF FOOD INDUSTRY IN UKRAINE

Olena Semenova[1], Tatiana Suleyko[1], Alina Siryc[1*], Olga Yevtushenko[1]

[1]Faculty of Biotechnology and Environmental Control, National University of Food Technologies, Volodymyrska str., 68, 01601 Kyiv, Ukraine

[*]e-mail: sao30.dn@gmail.com

Abstract

Implementation of the Environmental Policy of Ukraine contributes to the construction of the local wastewater treatment station at the food technology enterprises. For purification of such wastewaters it is possible to use anaerobic-aerobic integrated technology to ensure complete liquidation of impurities/pollutants. The aim of this article was to determine the optimal parameters of wastewater treatment and to eliminate the certain deficiencies of aerobic fermentation.

Experiments were conducted in the laboratory settings that included: methane tank, gas tank, aerotank-mixer and secondary purifiers. The subjects to recycling were sewage waters from dairy industry which were contaminated by COD 4,200 mg O_2/dm^3. The process took place in periodic and continuous modes. In the periodic mode the wastewater was fed into the setting once in a fortnight, in the realization of continuous mode - by little portions every hour. There was made the research of processes of biogas obtained through anaerobiotic digestion of alimentary production sewage in periodic and permanent modes with subsequent additional purification using aerobiotic fermentation.

It was established that continuous fermentation mode of wastewater flows is the most effective to get the additional source of energy - biogas. Investigated ways of intensification of the aerobic fermentation stage can increase the productivity of an aeration tank in the wastewater treatment, reducing respectively the environmental load in the region where a food industry enterprise is situated.

The proposed ways of intensification aerobic fermentation of waste water can improve the effectiveness of the cleaning process more than 99%.

Key words: Activated sludge, Wastewater treatment, Food industry enterprises, Aerotank, Aerobiotic fermentation, Safety.

1. Introduction

Most of the enterprises of food industry dump their wastewater into centralized sewer network, but due to the fact that this liquid waste may contain high concentration of pollutants, their effluents in city sewers are limited to requirements. Acceptance of wastewater in sewer systems is carried out in accordance with "Rules of acceptance of wastewater enterprises in municipal and departmental sewage of cities and settlements of Ukraine" [12]. For example, maximum permissible discharge standards of Kyiv stock water comprise approximately 500 mg O_2/dm^3 for the indicators of contamination (COD), while indices of stock water of dairy enterprises exceed these standards in several times.

At the beginning it is necessary to consider the basic principles of wastewater treatment for the food industry. There is a comprehensive technology that ensures the complete elimination of contaminants from the food industry wastewater. It combines mechanical, physico-chemical and biological principles. The latest include anaerobic methane fermentation and aerobic oxidation in aerotanks. Methane fermentation usually filters all or only the most concentrated part of it because a few of the highly contaminated water is diluted in the common flow. Pre-treated water after methane fermentation is sent to the general runoff, which typically is cleared by the aeration [13]. Moreover, the concept of "pre-treatment" refers to a sequence of process, not to its auxiliary character. As the level cleaning of methane fermentation is the main component stage of the chain in all cases, it can reduce the concentration of pollutants by 60 - 95% depending on the substrate (especially its saturation with biogenic elements) and the conditions of the process (including the temperature) [2].

Anaerobic technology has a number of significant advantages over aerobic one which is generally accepted.

Methane fermentation greatly expands the range of wastewater that is suitable for biological cleaning. It allows effective purification of the wastewater with COD over 2,000 mg O_2/dm^3, whereas the aerobic fermentation suits only for the water with a BOD of 2,000 mg O_2/dm^3 [3]. The anaerobic process is carried out with less use of biogenic elements, which is important when processing wastewater. Thus, runoffs with the ratio of the BOD_5 : N : P = (300 - 500) : 7 : 1 are suitable for anaerobic treatment. The same aerobic technology would add biogenic elements with adjusting of this ratio to 100 : 5 : 1 [17].

Anaerobic fermentation allows obtaining economically valuable biogas which contains 50 - 80% of the gaseous fuel methane [7]. The main factors that influence the content of methane in the biogas are the following: concentration and the kind of polluting substances, conditions of running a process (temperature, dilution speed). One of the simplest ways of applying the biogas is to burn it. More promising is the use of biogas to produce electrical energy, which can lead to the formation of our own energy base, which covers 40 - 50% of total energy costs. This is especially significant under conditions of the contemporary energy crisis in Ukraine. In particular it will improve the financial state of the food enterprises that will reflect respectively on the decrease of the cost price of their production [4].

Comparison between aerobic and anaerobic methods of cleaning showed that anoxic treatment of organic pollution can provide 94 - 96% of biogas in the form of methane and carbon dioxide and only 4 - 6% are converted into biomass. While during the aerobic processing - about 80% of the organic pollutants are converted into biomass and 20% are oxidized to carbon dioxide. There is also destruction of significant amounts of nutrients [7].

Activated sludge that accumulates in the methane tanks is a valuable product, enriched with vitamins of the group B. The active sludge concentration of vitamin B_{12} represents on average 45 - 50 mg/g of dry matter [19]. Sludge contains all the necessary animal waste elements (nitrogen, phosphorus, potassium and others). No eggs of helminthes, pathogenic microorganisms are killed in the process of the methanogenesis. Anaerobic activated is enriched by the biologically active substances including vitamins of the group B. That is why it is relevant to use it as a fertilizer and an additive to the feed for the farm livestock [1].

Nowadays, the enterprises of food and processing industry of almost all developed countries use the methanogenesis as primary stage of purification of concentrated wastewater. The treatment of concentrated wastewater from dairies through methanogenesis is widely used, and the effect of treatment is 80 - 85% for BOD [7].

It can be said that food technology enterprises purification wastewaters is possible by the use of anaerobic-aerobic integrated technology in order to ensure complete liquidation of impurities/pollutants. The aim of this article was to determine the optimal parameters of wastewater treatment and to eliminate the certain deficiencies of aerobic fermentation.

2. Materials and Methods

Experiments were conducted in the laboratory settings that included methane tank, gas tank, aerotank-mixer and secondary purifiers. The process took place in periodic and continuous modes. In the periodic mode the wastewater was fed into the setting once in a fortnight, in the realization of continuous mode - by little portions every hour.

There were used standard methods for the determination of the basic parameters of hydrochemical and technological water treatment (BOD), quantity of biogas methane content in it, the rate of dilution, load on activated sludge and its increase in aerotanks, depth of purification [9].

The subjects to recycling were sewage waters from dairy industry which were contaminated by COD 4200 mg O_2/dm^3.

Methane wastewater treatment was carried out at a temperature of 55 °C, which corresponds to the thermophilic range of temperatures. In periodic mode, a daily charge dose was 25% and 50% of the total volume of culture fluid of the reactor.

Fermentation time for runoff from dairy industry plant at 25% and 50% charge dose was 3 days.

Every series of experiments was conducted not less than in 3 repetitions. Statistically processed average parameter values of the determined magnitudes are represented in the tables and pictures. Statistical processing of numeric results of researches was done with a standard method that envisages the determination of: sample mean, median, mode, and also of the dispersion, mean and standard deviation [16].

3. Results and Discussion

Results of studies of the selected wastewater purification in periodic mode are shown in the Table 1.

The most intensive transformation processes of pollution and gas generation occur in the exponential (logarithmic) and stationary phases of growth of activated sludge microorganisms, as evidenced by the experimental data. There is observed a clear dependence between the processes of purification and synthesis of biogas.

Biogas largest excretion occurs at the maximum consumption of nutrients from the runoff. When raising the charge dose, the intensity of cleaning and gas generation reduces that confirms the classical idea of the activity of microorganisms under conditions of increasing content of pollutants [11].

Since, in practice, for recycling and purification of concentrated wastewater it is mostly applied a continuous fermentation mode, the purpose of the research was to determine the parameters at which the depth of purification and yield of biogas would reach maximum values, with simultaneous consideration of economic indicators. Basing on the results of previous research of the fermentation processes, the conclusion was made about the inappropriate use of large charge doses. That's why there were used charge doses in the range from 10 to 25% of the volume of culture fluid. The research results are presented in the Table 2.

The continuous fermentation has revealed that with the chosen speed of dilution there can be achieved a significant degree of purification.

Results suggest that the biggest level purification is achieved at the lowest rate of dilution and, conversely, higher rate of dilution leads to lower levels of digestion. The increasing rate of dilution leads to increase of the contaminants' number that affect the processes of assimilation of contaminants, the composition of microorganisms, their symbiotic interrelationships, etc. Therefore, at the higher rate of dilution a part of contaminants undergoes the incomplete way of decay to the end products of fermentation that affects the depth of digestion.

Continuous fermentation of concentrated wastewaters of dairy industry plant has shown a direct dependence of the production of biogas from the concentration of these contaminants in the wastewater.

Graphic presentation of dependence of biogas yield during purification process from the rate of dilution is shown on the Figure 1 below.

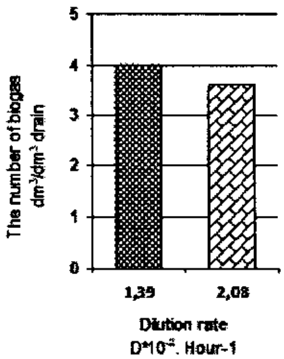

Figure 1. The dependence of the biogas yield in the purification process on the dilution rate

The methane content in biogas and the digestion depth of wastewater pollutants depending on the dilution rate are shown on the Figure 2. There is a clear conformity that quantitative and qualitative indicators of biogas worsen with the increase of dilution rate.

Table 1. The results of purification and gas generation during periodic fermentation of waste water, depending on charge dose

Wastewaters origin	Charge dose, %	COD_{final}, mg O_2/dm^3	Quantity of biogas, dm^3/dm^3 filter	Contents of CH_4, %	Level of the digestion, %
Dairy industry plant	25	195	2.30	73.3	95.4
	50	220	2.12	68.2	94.8

Table 2. The results of purification and gasification during continuous fermentation of wastewaters according to the dilution rate

Wastewaters origin	Dilution rate, $D{\cdot}10^{-2}$, h^{-1}	COD_{final}, mg O_2/dm^3	Quantity of biogas, dm^3/dm^3 drain	Contents of CH_4, %	Level of the digestion, %
Dairy industry plant	1.39	550	4.0	75	86.9
	2.08	680	3.6	73	84.0

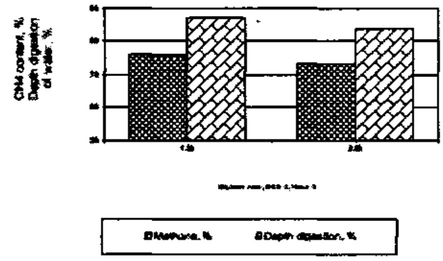

Figure 2. Content of methane in biogas and the depth digestion of wastewater dairy industry plant

When increasing the rate of dilution, there is growth of contaminants that are fed into methane tank and it makes the existing association of microorganisms adapt to the new conditions. It is known that the growth rate of methanogenic bacteria is lower than in the other part of the symbiotic group. Thus, increasing of the dilution rate can change the ratio between symbionts and methanogens with reducing of the latter. In addition, as a result of overloading in the system, there can be observed an inhibition effect of culture by the excessive number of nutrients or metabolic products formed during the decomposition of the former ones. We believe that under these conditions the process is directed towards reducing the capacity of biogas.

These considerations are confirmed when we consider the qualitative composition of biogas. The percentage of methane in biogas (as well as the quantity of biogas yield) depends on the speed of dilution. Since in the process of decomposition of pollutants carbon dioxide is generated (one of the components of the substrate, reduced by methanogens into methane), it is possible that the increasing rate of dilution leads to disorders in this mechanism, and some the carbon dioxide doesn't have enough time for the reduction process.

In addition, there were conducted researches on post-treatment of wastewater after methane fermentation using aeration (these results are indicated below).

Application of aeration for wastewater treatment is limited to the requirements for concentrations of contaminants, which must not exceed 2,000 mg O_2/dm^3 for the BOD. The studies made by the authors have shown that methane fermentation at the first stage of concentrated wastewater treatment was accompanied by a decrease in the content of pollutants. Since that, usage of the aerobic methods becomes economically justifiable [15].

For the aerobic post-treatment there were used wastewaters obtained after the methane fermentation. The main input indicators were the final values of COD of the culture fluid after methane fermentation.

Aerobic sludge treatment was carried out in periodic mode in the aerotank laboratory. Concentration of the sludge was 3.5 - 5 g/dm^3 (depending on the type of wastewater and level of the contamination). Results for the aerobic wastewater treatment with the activated sludge are shown in the Table 3.

Aerobic treatment of wastewater achieves a considerable depth of cleaning. Further aeration almost never contributes to the decrease of contamination that indicates the limits of possible cleaning under these conditions.

Load on the sludge has a direct impact on the final performance of the purification process. The increase of the sludge load leads to the decrease of the effectiveness of treatment. Theoretically, COD of treated water should be the same for each runoff at all values of the load on sludge, as the length of the aeration process has a different time, but in practice it isn't observed.

Experiments conducted by us showed that usage of aerobic-anaerobic technology of sewage treatment of dairy industry plant and also enterprises that work on its wastes provide practically whole removal of contaminants according to COD. Thus, the purification depth of wastewaters from dairy industry plant constitutes 99.2%.

Aerobic stage of the waste water purification is the essential part of the technological scheme of the elimination of contaminants in the indicated wastewaters. That is why one of the prime tasks of the perfection of the purification process is the intensification of aerotank functioning. It is linked with the increase of quantity of the substances that can't undergo biodegradation when increasing the load on the sludge (for example, these are surfactants which can get into wastewaters with detergents).

Perfection of the aeration tanks is performed by means of improving the conditions of contact of the reacting

Table 3. Results of wastewater aerobic purification

Wastewater origin	$COD_{beg.}$, mg O_2/dm^3	COD_{final}, mg O_2/dm^3	Time of the aeration, h	Silt load, g BOD/g	Level of cleansing, %	Increase of sludge, mg/dm^3
Dairy industry plant	550	20	8	0.215	96.4	203
	680	45	12	0.295	93.3	215

phases (pollutants, activated sludge, oxygen) to raise the overall speed of the cleaning process.

At such conditions there is the deeper oxidation of wastewater pollutants by the following methods [8]: increase of the sludge mass that is involved in the process of cleaning. This method has a very significant limitation: there is the limit of the sludge content (approximately 15 g/dm^3, while the best for traditional purification is 5 g/dm^3) which ensures the uninterrupted work of the secondary sedimentation tanks [6]. When increasing the sludge dose in the aeration tank to this limit, there can be improved the productivity and the quality of waste water treatment; acceleration of the process of biochemical oxidation by influencing the activity of microbial cells by physical factors, such as magnetic, electrostatic or electrodynamics fields. Electric current, for example, stimulates growth and enzymatic activity of activated sludge microorganisms, increases dehydrogenase activity from 24 to 50 mg/g completely dry matter (CDM) [10]. Besides using electric current of small capacity (approximately 8 - 10 microwatts) there can be achieved not only the increase of wastewater treatment efficiency, but also a certain acceleration of the process (on average 25%), which is very important under conditions where the water expenses aren't uniform [14]; acceleration of the process of aerobic fermentation using the method of biosorption, including cell immobilization etc. Attached microflora of the treatment facilities revealed much more biochemical activity, than freely floating flakes of sludge in the liquid environment. The yellow saponite was elected as a carrier, as crushed fraction approached in its size to the sludge flakes; at low concentrations of adsorbent (1 g/dm^3) purification is accelerated to 25%; and greater concentration of yellow saponite (upto 4 g/dm^3) led to the reduction in the purification period to 50%.

During the usage of wastewater treatment facilities on diary enterprises, development of new technological processes and new types of equipment on such enterprises, it is obligatory to take measures that exclude or reduce to acceptable limits the possible impact of physical, chemical and biological dangerous or harmful production factors that could involve workers.

So during the process of cooling of circulating water physical factors are: moving machines and mechanisms (when servicing pumping stations); moving parts of production equipment (when servicing wastewater biological or mechanical treatment facilities and sludge treatment); objects falling from a height, that destroy working constructions, increased air pollution of the working area of wells, collectors, canals, or possible leakage of gases from gas bags or tanks (when working in wells, tunnels, canals); increased or decreased air temperature of the working area (when servicing sewerage networks, mechanical and biological wastewater treatment facilities and sludge treatment, and during the process of cooling circulating water); increased air humidity of working area (when servicing pumping stations, or biological and mechanical wastewater treatment facilities); increased or decreased air mobility of the working area (when servicing sewerage networks, biological and mechanical wastewater treatment facilities and sludge treatment); increased voltage in the electrical circuit, the short-circuit of which can happen through the human body (when servicing pumping stations, sewerage networks, mechanical and biological wastewater treatment facilities and sludge treatment, during the process of cooling circulating water and disinfecting of wastewater); increased noise level in the workplace and increased vibration load on the worker, the absence or lack of natural light, insufficient illumination of the working area when working in wells, tunnels, canals; when disinfecting wastewater occurs increased levels of ultraviolet radiation (when servicing pumping stations.

Chemical factors are toxic substances like chlorine and ozone, which penetrate into the human body through the respiratory system, gastrointestinal tract, skin and mucous membranes when servicing pumping stations, mechanical and biological wastewater treatment facilities, and when disinfecting wastewater.

Biological factors include pathogenic microorganisms and products of their vital activity when servicing pumping stations, mechanical and biological wastewater treatment facilities and sludge treatment, and during the disinfection of wastewater.

4. Conclusions

- The problem of wastewater treatment of the food enterprises stays unresolved in Ukraine even today [6]. Authors proposed the usage of the biological process of the wastewater treatment of the dairy industry plant by methane fermentation and aerobic fermentation. Efficiency of the investigated methods constitutes more than 99% that is more much higher than on any existing wastewater treatment station of the household [5]. There were proposed methods of perfection of aerobic fermentation stage to accelerate (in 1.5 - 2 times) and to increase the efficiency of the purification process.
- The proposed methods of intensification of aerobic fermentation of wastewater can be used in water purification stations of any industrial enterprise that works with organic raw materials, which use the aerobic fermentation process of the wastewater

pollutants in the complex anaerobic-aerobic or basic (traditional) purification stage [14, 18].

- Thus, the results convincingly showed that the continuous mode of fermentation of dairy industry plant wastewater and productions, working on its wastes is the most effective among the existing methods and allows to achieve a significant removal of pollutant's concentrations and to get an extra source of energy - biogas.

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